Document made available under the Patent Cooperation Treaty (PCT)

International application number: PCT/IL05/000292

International filing date: 15 March 2005 (15.03.2005)

Document type: Certified copy of priority document

Document details: Country/Office: US
Number: 60/600,811
Filing date: 12 August 2004 (12.08.2004)

Date of receipt at the International Bureau: 05 September 2005 (05.09.2005)

Remark: Priority document submitted or transmitted to the International Bureau in compliance with Rule 17.1(a) or (b)

PCT/IL 2005 / 000292

21 AUG 2005

PA 1347837

THE UNITED STATES OF AMERICA

TO ALL TO WHOM THESE PRESENTS SHALL COME:

UNITED STATES DEPARTMENT OF COMMERCE

United States Patent and Trademark Office

July 25, 2005

THIS IS TO CERTIFY THAT ANNEXED HERETO IS A TRUE COPY FROM THE RECORDS OF THE UNITED STATES PATENT AND TRADEMARK OFFICE OF THOSE PAPERS OF THE BELOW IDENTIFIED PATENT APPLICATION THAT MET THE REQUIREMENTS TO BE GRANTED A FILING DATE UNDER 35 USC 111.

APPLICATION NUMBER: *60/600,811*
FILING DATE: *August 12, 2004*

By Authority of the
Under Secretary of Commerce for Intellectual Property
and Director of the United States Patent and Trademark Office

T. LAWRENCE
Certifying Officer

Approved for use through 01/31/98. OMB 0651-0037
Patent and Trademark Office; US DEPARTMENT OF COMMERCE

PROVISIONAL APPLICATION FOR PATENT COVER SHEET

This is a request for filing a **PROVISIONAL APPLICATION FOR PATENT** under 37 CFR 1.53 (b)(2).

Docket Number	28433	Type a plus sign (+) inside this box ->	+

INVENTOR(s) / APPLICANT(s)

LAST NAME	FIRST NAME	MIDDLE INITIAL	RESIDENCE (CITY AND EITHER STATE OR FOREIGN COUNTRY)
SLATKINE	Michael		Herzlia, Israel
KARASIKOV	Nir		Haifa, Israel
TAMIR	David		Haifa, Israel

TITLE OF THE INVENTION (280 characters max)

ENERGY SAVING COMMUNICATION WITH REMOTE SENSORS AND INFORMATION STORAGE DEVICES

CORRESPONDENCE ADDRESS

Martin Moynihan
c/o ANTHONY CASTORINA
2001 JEFFERSON DAVIS HIGHWAY
SUITE 207

STATE	VIRGINIA	ZIP CODE	22202	COUNTRY	USA

ENCLOSED APPLICATION PARTS *(check all that apply)*

☑ Specification	*Number of Pages*	64	☑ Applicant is entitled to Small Entity Status
☑ Drawing(s)	*Number of Sheets*	11	☑ Other (specify) 3 Claims

METHOD OF PAYMENT OF FILING FEES FOR THIS PROVISIONAL APPLICATION FOR PATENT *(check one)*

☐ A check or money order is enclosed to cover the filing fees

☑ The Commissioner is hereby authorized to charge filing fees and credit Deposit Account Number: 50-1407

FILING FEE AMOUNT ($): $ 80.-

The invention was made by an agency of the United States Government or under a contract with an agency of the United States Government.

☑ No

☐ Yes, the name of the US Government agency and the Government contract number are: ____________

Respectfully submitted,

SIGNATURE *Martin J. Moynihan*

12 August 2004
Date

40,338
REGISTRATION NO.
(if appropriate)

TYPED or PRINTED NAME Martin Moynihan

☐ Additional inventors are being named on separately numbered sheets attached hereto

USE ONLY FOR FILING A PROVISIONAL APPLICATION FOR PATENT

Burden House Statement: This form is estimated to take 2 hours to complete. Time will vary depending upon the needs of the individual case. Any comments on the amount of time you are required to complete this form should be sent to the Chief Information Officer, Patent and Trademark Office, Washington DC 20231. DO NOT SEND FEES OR COMPLETED FORMS TO THIS ADDRESS. SEND TO: Box Provisional Application, Assistant Commissioner for Patents, Washington, DC 20231.

ENERGY SAVING COMMUNICATION WITH REMOTE SENSORS AND INFORMATION STORAGE DEVICES

This invention is related to US Patent Application No. 60/552,728 filed on March 2004, and WO0232150.

Inventors – Michael Slatkine; Nir Karasikov; David Tamir.

Assignee – IRALink Ltd.

1. Field of the invention

The invention is related to communication with multiple remote sensors or smart information and identification storage devices in general and particularly to energy saving communication, which will allow the batteries installed in the sensors or devices to last longer.

2. Background of the invention

Remote sensors are widely utilized in a variety of applications which include among others: chemical sensors located in dangerous locations such as a chemical reactio n chamber; air and water pollution sensors whereby the sensor is floating in the air or on water, temperature sensors such as in ovens, chemical reaction chambers, nuclear reactors; strain gages such as on the top of a very high building, a top of a construction such as a bridge; a video camera in a hazardous material facility, an array of video cameras outside a protected facility such as a prison or a military facility or along a fence , a camera in a battle field . All sensors practically store the infomation collected by them in some memory element and communicate the information to the information user. Storage time may vary. Even "real time " transmission mostly utilizes a very fast memory as a relay between the sensor and the transmitter. All sensors and information storage devices (which will be referred as sensors hereafter) utilize some forms of energy source, which may be electrical batteries. In all these cases there is a necessity to utilize energy saving components in order to avoid as much as possible battery replacement, which may be inconvenient. In some applications, the number of sensors may be very large, to the extent of making battery

replacement impractical. In other cases, change of the battery is so inconvenient that the introduction of the sensor into the market depends on energy saving, namely on very low consumption of energy. An energy-consuming component in all sensors is the transmitter, which transmits the information gathered by the sensor to a remote station, which receives the information. Such a transmitter can be a microwave transmitter, which is often, utilize in " Bluetooth " transmitters. It would be advantageous to improve the operational properties of remotely deployed sensors or information storage devices by reducing the energy consumption of the transmitter, which transmits the collected information.

Some sensors such as chemical sensors often transmit low bandwidth signals, which may be as low as 10 Hz in the case of detection of a single type of molecule in the time interval of a few seconds. Some sensors may store the information for one day and transmit the information at a very low rate such as 1 Hz. Some other sensors such as a real time video cameras may transmit information at a rate as high as 10 Mega Hz. As a result, in many sensors, the modulator of the transmitted signal should be capable of modulating signals at a very high repetition rate.

There is also a wide variety of operating ranges of remote sensors. Some chemical sensors, such as a sensor located in a hazardous reaction chamber may be monitored from a distance of a few meters. On the other hand, sensors, which are deployed around a protected facility, may be monitored from a distance of a few tens of meters. Sensors in a battlefield may be monitored from a distance of a few hundred meters or a few kilometers. Sensors located in the sea may also be operated from a few kilometers.
Remote sensors or information storage devices can be deployed in very large quantities. Examples are: smart remote identification and authentication cards in the hands of people in a crowd in a secured mall or airport entrance (the card serves as a sensor to its holder features), multiple pollution sensors, multiple of cameras in a security facility among others. There is a need to communicate with all sensors almost simultaneously in an efficient way without necessitating too much electrical power in the information gathering station as well. Also establishing the communication channel (such as aiming an optical beam) should be quick.

In many cases a sensor may accumulate information for a time duration, and only later release the information to a user. As an example of that specific mode, a commercial consumer digital camera such as utilized by

tourists and produced by companies such as Nikon, Fujinon and others, accumulate a number of pictures and store them in a flash memory. The flash memory may be removed and provided to a picture development center for printing. The process of removing the memory and physically providing it to a development facility is time consuming and often requires waiting in a waiting line. It would be advantageous if the stored information could be transmitted via wireless communication to the printing center. This would enable camera users to pass by a printing center and instantly transmit the pictures for printing, even through the shop glass window, when the shop is closed. However, transmitting the information is energy consuming and cameras batteries normally don't last long enough. An energy saving communication channel between a camera and an information receiver is in need.

The use of energy saving retromodulators in smart remote identification cards in conjunction with biometric information has been described in application 27758 by the authors of the current invention. A smart card is a sensor to biometric information, which should be transmitted to a security check station (which may be the entrance of a café, of an airport or of a bus as examples). There are cases where it would be beneficial to utilize a camera as the sensing element in the smart card, and biometric information as the identifying information. Other smart cards are described in application 27758.

Retroreflectors, which incorporate modulators, have been described in patent application 27758 and WO0232150, authored by the authors of the current invention. Retroreflectors are also described in US patents **6,353,489** **5,355,241** and **6,624,916** and in patent **DE**19652920. The above-mentioned patents are focused on friend or foe identification devices, where a prestored modulation code is stored and applied to the retromodulator. There is no sensing element related to the device, and modulation rate is usually low.
Other patents related to retro communication are:

- The German patent DE 19652920 describes a retro, which can be modulated and serves as a friend or foe identification device.
- 5606458 is a HUD illumination system using retro.
- 20010000980 is a coded passive label.
- 20020105065 and ...5232 are RF based.

A relevant patent search appears in Annex 1.

The utilization of electromagnetic waves with wavelengths ranging between the infrared range and the microwave range (millimeter waves – Tera Hz frequency range) is well known in the prior art. For instance a system that detects both metal and non-metallic weapons using tera Hertz light has been developed by technology firm TeraView. Thus radiation in the visible, IR, mm and tera Hz could be used in the invention of low power retro modulation.
Furthermore ultrasonic radiation can also be retro modulated facilitating non-electromagnetic communication link. This is one of the embodiments of the present invention.

3. Objectives of the invention

1. A method and apparatus for the sensing of a physical entity and communicating the information about the sensed entity to a remote station, said sensing method and apparatus incorporates a sensor subassembly which is integrated with an optical retromodulator, and a transceiver subassembly located at a distance, said transceiver incorporates a light beam transmitter and a mean to detect and demodulate the light modulated and retroreflected by the retromodulator.
2. Said sensor as in 1 may sense any entities in the list of air pollution, toxic or hazardous chemicals in the air, toxic or hazardous chemicals in water, temperature, an image, biometric information, strain, pressure, liquid or gas leak, vibration and so on.
3. Said sensor as in 1 modulates the said retromodulator at any rate between typically 0.01 bits / sec to 10 Megabit /sec.
4. Said transceiver as in 1 is located on the ground.
5. Said transceiver as in 1 is located on an airborne vehicle.
6. Size of said airborne vehicle as in 4 is between 4 meters and 1 mm.
7. The velocity of said airborne vehicle is between zero (balloon or smart dust or helicopter) and 1500 km/hour (as in a rocket).
8. Transceiver as in 1 is a multidirectional (broad angle) transceiver.
9. Multidirectional transceiver said in 8 consists of a multitude of segments; said segments may be of Cassagrain type transmitter with a receiver in front of said Cassagrain transmitter.
10. Radiation emitted from each section of transceiver said in 8 is eye safe.

11. Transceiver said in 1 continuously emits essentially low power radiation to detect retromodulator said in 1, and increases emitted power in order to detect information retromodulated by retromodulator said in 1 with high enough signal to noise ratio once retromodulator has been detected.
12. Transceiver said in 11 switches active detector once retromodulator is detected by another transceiver in the transceiver array.
13. Sensor as in 1 and retromodulator as in 1 are both located on air born vehicle (sensing is performed from an airborne vehicle and not from ground.).
14. Transceiver assembly on airborne vehicle or on ground communicates with a multitude of deployed sensors as in 1.
15. Transceiver light source is any in the list of LED or an array of LEDs, or a laser or an incoherent lamp, or a mm or tera Hz radiation.
16. Transmitter in transceiver as in 1 emits light at more than one spectral bands or lines, said retromodulator as in 1 spectrally multiplexes information by retromodulating some information at one spectral band and other information with another spectral band, said transmitter source may be any of light sources in the list of: home use incandescent lamp, spot halogen lamp, spot high intensity metal halide lamp, multi spectral LED or mm or tera Hz radiation.
17. Airborne transceiver as in 5 is scanning the ground in order to compensate for airborne vehicle movement and keep the retromodulator in the transceiver long enough time to enable the use of a smaller information bandwidth.
18. Transceiver said in 1 incorporates a fiber or a fiber bundle; said fiber or fiber bundle is brought at a close distance of a sensor and retromodulator.
19. A retromodulator integrated with a digital camera.
20. Said digital camera in 19 stores a traffic picture, analyzes the traffic picture and later on retroreflects picture into a transceiver station according to a criteria stored in the digital camera or in an electronic device attached to the camera.
21. Said digital camera in 19 is on a security fence, said camera takes an image at specific time intervals and retroreflects the image information.
22. Said digital camera in 19 is located on an airborne vehicle.
23. Camera said in 22 has a protective mean against hazardous materials and camera is located in a hard to access area.
24. Said camera in 19 is a commercial consumer camera.

25. Said camera is on a smart biometric identification device (or card), said camera takes pictures of the smart card holder, said camera incorporates a mean to analyze the biometric information collected by said camera, said smart card already stores biometric information on card holder, said smart card incorporates a retromodulator for the retromodulation of the card holder biometric information to a transceiver for comparison of stored biometric information to currently imaged biometric information.
26. Said smart identification card incorporates both a camera and a microphone and said identification is based in both biometric image visual data and voice analysis.
27. System which comprises of a camera located in the entrance of a secured gate (such as bus entrance, air port gate), said camera can take a picture of an identification smart card holder and analyze biometric information acquired from said picture, said identification smart card incorporates a memory, said memory pre stores biometric information on the card holder, said card also incorporates a retromodulator which can be modulated with the pre stored biometric information, and said system also incorporates a transceiver (located on the entrance or gate) , said transceiver is capable of illuminating the card and retrieve the biometric information from card , and said system also incorporates a computer, which is capable of comparing the biometric information acquired by the camera to the pre stored biometric information.
28. System as in 27, whereby said camera is replaced by a microphone or whereby both a camera and a microphone are use.
29. A system for the detection of leaks in sewing pipes, said system incorporates a fiber transceiver and retromodulator sensors are located on the walls of the pipes.
30. A pollution monitoring system, said system comprises of a miniature Helium or vacuum balloon, said balloon is floating in an atmospheric region suspected of being polluted, said balloon incorporates a retromodulator, said retromodulator is connected to a pollutant sensor, said system also incorporates a transceiver.
31. System as in 30, said modulator modulates at a frequency, which enables the discrimination between ambient light and light emerging from the pollution sensor.
32. Pollution monitoring system whereby a multitude of balloons as in 30 are released to the atmosphere.
33. An optical retro modulator, which incorporates solid-state quantum dots.
34. An optical retromodulator, which incorporates a liquid crystal.
35. A transceiver, which incorporates aiming assembly as in figure 6.

36. A transceiver that is capable to redirect the retroreflected beam.
37. A friend or foe (FOF) identification device, said FOF incorporate a sensor which senses the device holder (as opposed to pre stored data), said device also stores pre stored data, said device incorporates a retromodulator as in 1 and is responding to light emitted by transceiver as in 1.
38. FOF device, said sensor is any one of the list of microphone, camera, skin sensor, biometric sensor.
39. Any of 1 -38, said electromagnetic wave is in the mm wavelength region (tera Hz).

4. Description of the figures

Figure 1: The deployment of energy saving sensors in a remote site and the retrieval of the information with a miniature air born vehicle (MAV).

Figure 2: Details of an optically triggered nano technology semiconductor retro modulator.

Figure 3: The electrical activation of the active nano material
Figure 3a: Represents the same concept in a fiber.

Figure 4: A fiber bundle base retro modulator sensor.

Figure 5: The operating principle of the fiber based retro modulator sensor.

Figure 6: A device, which assists in aiming the transmitter beam into the retro reflector

Figure 7: A security beam designed to avoid fooling the system by potential intruders.

Figure 8: A commercial digital camera equipped with an energy saving retromodulator for the fast downloading of pictures into a distant receiving station.

Figure 9: A camera in a smart identification device with a retromodulator for energy saving transmission of identification data.

Figure 10: A home use multi spectral spot halogen lamp serving as the light source in the transceiver in a multiplexing energy saving retromodulator system.

Figure 11: A mm wave retromodulator based sensor located in a region opaque to infrared light but transparent to mm waves such as a sensor buried in the sand or a sensor located in a suitcase.

Figure 12: A retromodulator as a warning signal for bicycles or motorcycles or pedestrians at night. The flickering retroreflection of the approaching vehicle will draw the attention of the driver.

Figure 13: A flexible retromodulator implemented as flickering stripes attached to helmets or coats or shirts with the intention to draw attention or as FOF.

Figure 14: A wide bandwidth retroreflection using of the shelf MEMS device with flapping mirrors.

Figure 15: A corner cube design for the mm waves using a resonant piezo material to alter the flatness of the corner cube.

5. Description of embodiments

The operating principle of an energy saving optical retromodulator has been described in patent application 27758 and is described in PCT patent application WO0232150.
We summarize it as follows: An optical source, which is a sub assembly of a transceiver, emits light towards an electronic information source. The angular divergence of the transmitted beam may be very large. The information source comprises of a retroreflector (which in most cases comprise of a lens or lenslet array and a mirror), and a modulator. The role of the modulator is to modulate the retro reflected beam. The retro modulator may consist of an element, which modulates the properties of the reflecting mirror, such as a MEMs device as described in Annex 2. Either vibrating the mirror or modulating its reflection modulates the retroreflected light. Another way to modulate the retro reflected light is to add a liquid crystal in front of the retro reflector or add a nano particle "

quantum dot " saturable absorber, or other active nano material, which will be described there after.
The receiver, which is integrated with the transmitter, receives the retromodulated light and demodulates the received signal.
The energy saving features of an optical retromodulator stems from the fact that energy is invested in the modulation process only and not in the generation of an electromagnetic wave, which carries the information toward the receiver. The carrier energy is generated by the transceiver, which is located in a site, which doesn't depend on energy saving features. Some of the application, which were described in patent application 27758, and WO0232150 are biometric remote identification with a smart card, communication such as Internet communication between a PDA (palm, cellular phone, digital camera) and the rest of a LAN.
The integration of an energy saving retromodulator to a digital camera is of great interest. Battery consumption of digital cameras is a common major problem with digital cameras. The transfer of pictures with a flash memory card requires a card reader, which is not always available. It would be useful to enable the wireless transmission of the pictures content to a devic e (laptop, desk top computer) while consuming minimal energy. This can be done by integrating a retro modulator to the camera and installing a transceiver on the computer. The present invention covers embodiments based on non-IR radiation such as mm wave, tera waves and ultrasonic radiation. Low power retromodulation can be implemented with all of these.

Figure 1 presents an application and system, which is a model for a few applications sharing similar features.

Figure 1 shows the deployment of sensors 1 in a remote location 2. Such remote location 2 may be an agriculture field, a city street, the periphery of a fence, a battlefield or the sea surface or a residential room among others. Sensors 1 (single or multiple) consist of a sensing element 3, which modulates the retro modulator 4, resulting in the modulation of the light beams 5.

The physical features which are sensed by the sensing element 3 may be the moisture of the ground for agriculture purposes, the concentration level of a chemical poisonous agent in the case of protection from chemical warfare or terrorism, pollution level for the protection of the environment while dealing with ecological problems, water pollution, the strain on a metallic beam which serves to reinforce a building or a bridge, the temperature in a cooking oven or an image stored in a security camera or a traffic speed detection camera among many others. In the latter case,

the sensor is a camera. Sensors, which measure each of the mentioned above quantities, are well known in the state of the art by any skilled engineer.

In one embodiment of the invention, the transceiver, which collects the information from the sensors 1, is located on a miniature airborne vehicle (MAV) 6 such as an unmanned airplane. Such airplanes are being built with different sizes, which range from a few meters to a few millimeters. The transceiver 7 consists of an array of Cassagraine transceivers as described in application 27758. Each transceiver continuously radiates low-level light, the role of which is to detect a retroreflector unit. The continuous emittance of low-level radiation saves the necessity to utilize a scanner, which may also consume too much energy. The operating bandwidth for the process of locating retroreflectors is low since no information is to be detected, excluding some basic modulation, which helps to discriminate the retroreflector from the background. Once the receiver in one of the transceivers detects retroreflected light from a retroreflector, a signal is generated, a signal which increases the level of the light emitted by the transmitter in the transceiver. The angular divergence of the emitted beam is Theta. Theta should enable to cover a large enough area in the vicinity of the retroreflector, in order to assure long enough communication time during the propagation of the MAV, which travels at a velocity V.

Example of an MAV system:

A typical velocity of an MAV is 60 Km/hour (~ 15 m/sec). A typical operating height of an MAV is 200 m. In order to establish a communication channel for a duration of ~ 2 second, the emitted beam divergence Theta should be ~ 2/10 radians (~ 12 degrees).
A low weight (less than 1 Kg) transceiver of 50 mm receiving optics and 100 mm emitting optics could be built and installed on the MAV. A 1-Watt diode laser operating at 900 nm is incorporated in the transceiver. The retroreflector diameter is 50 mm as well. The reflected divergence is 5 milliradians, which is over X10 times the diffraction limited divergence. The sensors, in the said example, are detecting a chemical agent. The information bandwidth is lower than 1000 Hz (based on the necessity to measure spectral properties of various agents in the duration of 1 second). The detector incorporated in the receiver (in the MAV) is a PIN Si photodiode with a current response of 0.5 A/Watts, a dark current of 2 nano amps. A load resistor of 100 Ohms is used. Based on these specifications, the signal to noise ratio in the detector can be calculated according to the equations:

(1) P(received)=P(transmitted)*(d retro^2)*(d rec ^2) / (Theta ^2 * Theta(retro) ^2 * D^4)
(2) NEP= (2*id*q + 4*k * T / R)^ 1/2 * B^ 1/2 * 1/r
(3) S/N = P(received) / NEP

Where (d retro) and (d rec) are the retro and receiver diameters respectively, NEP is the noise equivalent power of the detector, R is the photodiode load resistor and r is the optical transmission. Applying the S/N equation yields S/N ~ 15.

We have assumed a 5 -milliradian divergence of the retroreflector optical aperture. We have also assumed an overall optical transmission of 10%. A signal to noise ratio of 15 enables communication with a very low bit error rate. It must be emphasized that the operating range of an MAV system may be much longer, and that also smaller MAV may be utilized. The range of applications is wide. A small MAV may utilize a 5 watts source and still operate with a reasonable S/N.

Second example of MAV system:

The signal to be transmitted is a video signal generated by a camera in the sensor. The camera may take a p icture every 10 seconds, thereby reducing the normal video bandwidth of 5 MHz to 500 KHz. The emitting laser divergence is reduced to ~6 degrees (~ 0.1 radian). The signal to noise ratio is now ~6.

Third example of MAV system:

The signal to be transmitted is a real time 5 Mhz video signal. The transmitter divergence is reduced to 1 degrees, (~ 20 milliradians). As a result the signal to noise ratio is 67. In order to enable the MAV to operate with a 1-degree transmitter divergence, there is a need for a tracker, which will keep the transmitter aimed at the retroreflector.

Fourth example of a MAV system:

The MAV is a miniature helicopter 8. The advantage of using a miniature helicopter is the small velocity, which enables the increase of the divergence angle Theta. The helicopter may stay a long time on a single site, thereby avoiding the necessity to switch transceivers or to utilize a tracker, which will stabilize a transceiver on a retro and compensate for the MAV velocity. Low velocity MAV may be designed in additional ways, which are not necessarily based on the helicopter principles. A

device could float in the air, by creating a lightweight balloon filled with Helium or completely evacuated. Nano structured floating sensor were recently publicized.

In another embodiment of the invention, a retroreflector 9 is installed at the back of the MAV. A transceiver 10 is located far away from the MAV, in a control station. That embodiment is preferable in cases of very small MAV, where the MAV is battery operated and should be energy saving.

An MAV which is an excellent candidate for use of the energy saving retromodulator according to the current invention is any miniature MAV which may fly in a closed room or hall and performs inspection tasks such as sniffing for smoke or hazardous materials. The smaller the vehicle, the more acute is the need for energy saving communication. Sniffers are normally operated at a low information bandwidth, much lower than ~ 50 Hz (assume for example 5 types of pollutants of interest, each with 10 specific features such as 10 specific spectral absorption bands, samples every 1 second. Using material sensitive sniffers, such as FET with a material sensitive electrode, can further reduce the bandwidth).

An example of a confined area MAV is a small balloon filled with Helium. A 1 cubic centimeter balloon could carry a load of 1 gram. If such a balloon is equipped with a 0.1 gram sensor and a 0.5 gram retro modulator and a 0.4 gram low power battery or solar cell device, the balloon could float in the room and constantly provide information to a transceiver located in the room. As a result, size and energy consumption are small.

Figure 6 presents an accessory, which assists in the aiming of the transmitted beam toward the retroreflector. The described accessory is utilized both in a stationary condition where a tracker is not utilized (such as on a helicopter) and also in the tracking process. The beam 75 emitted from the transceiver has to hit the retroreflector 81. A beam splitter 78 is located in the beam path. A small percent (such as 5%) of the energy is reflected and hits a corner cube 77 to produce the beam 80, which is focused through a lens 82 to produce a spot 83 on an image plane. On the other hand, light reflected from the retroreflector 81 reaches the beam splitter 78 and is reflected in the form of a beam 85 to form a spot 84 on the image plane. The merging of spots 83 and 84 is a prerequisite for the beam 77 to hit the retroreflector 81. It should be appreciated that the usefulness of the assembly described in figure 6 is in conjunction with

various sensors of the spots 84 and 83. The sensor could be a CCD focal plane array, and an electric motor can steer the beam 75 with the aid of a control unit, which receives signals from the CCD, and a program, which assures that the distance between 83 and 84 is gradually reduced.
The utilization of the accessory of figure 6 as part of the transceiver design in embodiments of the current invention is of great assistance in many applications. This is particularly important in the cases of a retromodulator in the back of an MAV and a great distance between the MAV and the transceiver.

A fast quantum dot (nano particles) retromodulator

Several approaches to light modulation, based on nano technology, are feasible (Workshop on Nanoscience for the Soldier, ARO 2001, www.aro.army.mil/phys/Nanoscience/sec4nano.htm):

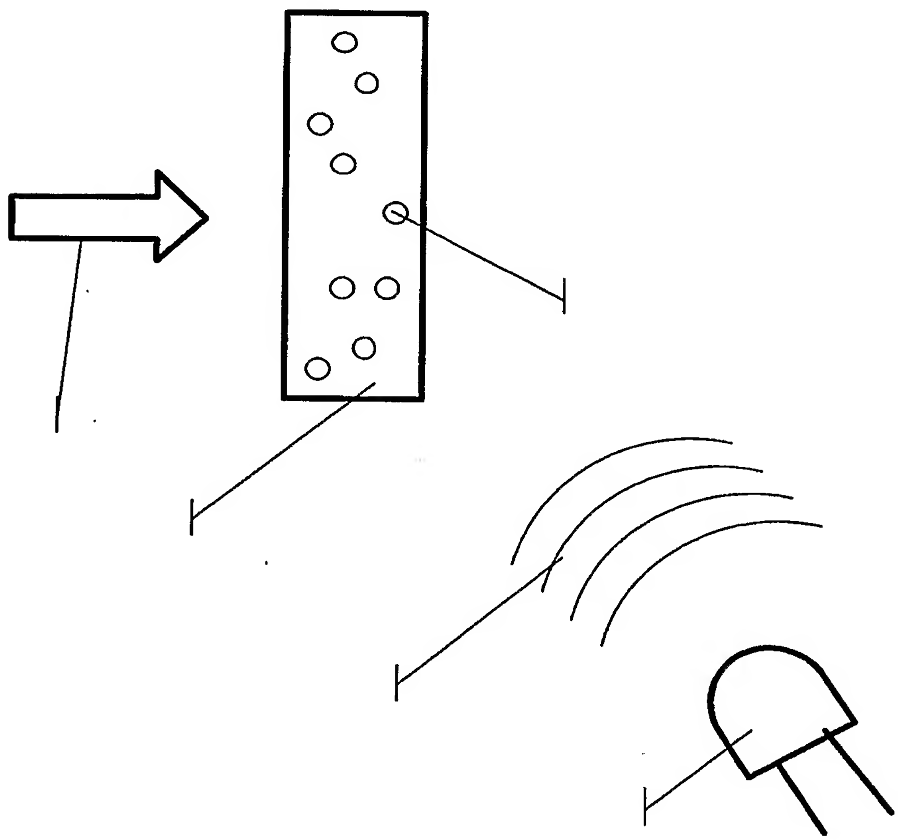
1. Nano-structured surfaces for alignment of LCD (Liquid Crystal Displays) (ferroelectric LC's are fast and would provide useful displays.) could be used for modulation.
2. Encapsulated liquid crystals (to provide for example holographic LC grating beam steering)
3. Direct scan using "nems" (nano-electro-mechanical devices) for steering.
4. Enhanced emission with structured surfaces (100x) = lower power consumption and increased lifetime, lower weight of displays are compatible also with modulation.
5. Charged nanotubes arrays in vacuum for low voltage opera tion.
6. Nano-structure – in pixels, Quantum well/wire/dot emitters, or atomic clusters
7. LCD nano molecules – nanotubes as active elements
8. Photonic bandgap (PBG) materials for reflective image from visor; Uniform, omnidirectional refelctivity
9. Active camouf lage: e.g. PBG's, or electronically controlled nanolayers to alter reflectivity (e.g. MQW's or PBG's), or electrically addressed LC's in suit.

Colloidal semiconductor nanocrystals (NCs) is one of the groups that can be considered for modulation, due to their quanatized electronic states. In other words, these NCs may act as an optical modulator. Saturation may be obtained by optical pumping, or by injection of carriers from the outside world.

In the said modulator the normal state is opaque absorbing the light in the required wavelength, upon excitation, either optical or electrical the modulator changes to transparent.

The mechanism is described in the following two figures:

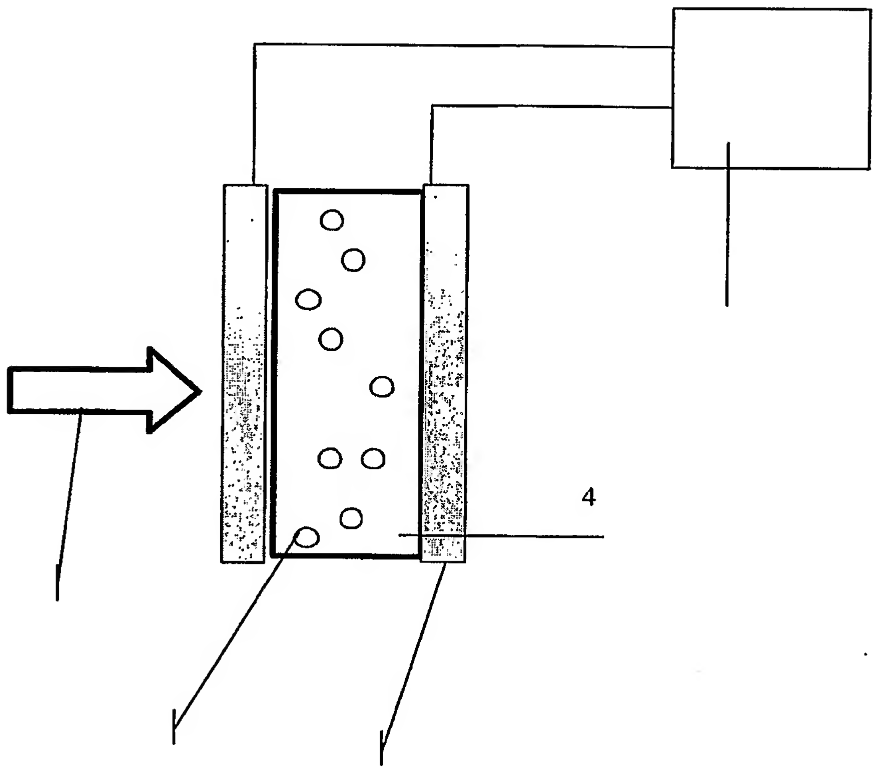
Fig 2:



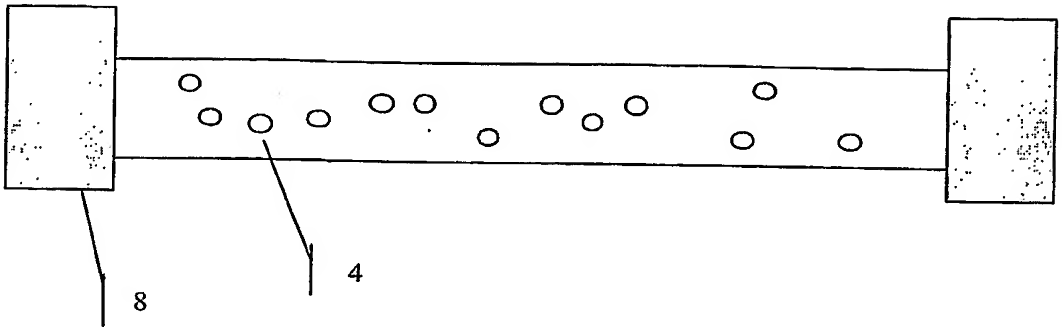
Where an incoming light beam (1) is aimed at the active nano component (per the above list) (2) doped substrate (3). The substrate is opaque and the incoming beam (1) is absorbed. When the local light source (4) is activated the NC (2) are energized and the substrate becomes transparent. The incoming beam (1) can thus pass through and be used for retro modulation as well as for other modulation purposes. In this embodiment, the local light source (4) is of much lower energy compared to the energy

that would be needed to transmit IR energy to secure a given signal level at a distance R.

The electrical control embodiment is described in the following figure 3:



Where the active nano component (2) doped substrate (4) is covered with transparent electrodes 6. An electric signal generated in the generator (7) injects electrons to the substrate (4) or apply voltage, which consequently is excited and becomes transparent.
Another embodiment relates to the embedding of the active nano component in an optical fiber. This fiber can then be used as an optical modulator using either of the two approached described above.
This is shown in Figure a:



Where the substrate (4) is an optical fiber with two connectors (8) at the two ends.

Fiber based retromodulation energy saving sensors

Figure 4 presents a different method and apparatus for communication with the energy saving retro modulator. The communication channel is a fiber or fiber bundle based channel. Illumination 55 is launched into a fiber bundle (or single fiber) 54. The light propagates along the fibers and 50 and 51 and hits the retroreflector unit 52 with a sensor 53. The retroreflected beams will impinge on the exit side of the fiber bundle and propagate back to the original entrance of the fiber with high efficacy since angles are kept in both retro reflection process and internal reflection in the fiber. The reflected light is diverted toward a detector. The retromodulator is modulated with a signal, which is sensed by the sensor 53 or generated on the retro reflector. Figure 5 depicts the conservation of angular property of the beams involved in the fiber bases sensor.

There are many applications of the fiber based retro modulator sensor. Among them: a) bringing the transceiver beam into a hazardous environment where the concentration level of chemical products in the air or in a liquid have to be monitored. B) Communication with a sensor, which is under the water. C) "Last mile " retrieval of information: Conventional communication between two locations is not made possible (such as between two buildings) and one side should be energy saving.

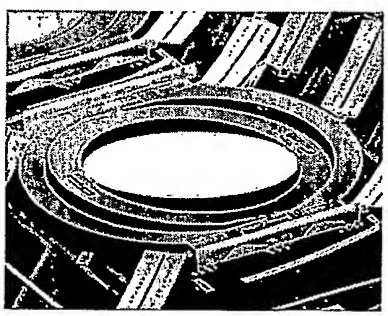
A specific example of the great advantage of using an energy saving retromodulators and fibers according to the current invention is the sensing of leaks in sewage systems. The development of cracks in major sewage pipes poses a severe threat to the environment. Once the pipe is leaking, large amounts of waste materials may spill to the sea or

proliferate to underground water reservoirs, resulting in long term pollution. The energy saving solution is the installation of crack sensors along the inner surface of sewing pipes. Each sensor is connected to an energy saving retromodulator. A fiber guide or fiber bundle is guided along the pipe and transmits light. Once light hits a retromodulator a signal is transmitted, which describes the pipe condition, the light is returned to the fiber and to the transceiver
The fibers in conjunction to retromodulation according to the present invention, offer an ideal low power, non-line of site solutions to retrieve remote sensors information. This is very applicable to industrial monitoring in processes, which require intrinsically safe conditions. The whole link is low power, low current and with no galvanic connection. Furthermore another aspect of the present invention is the ability to supply all the necessary energy for the remote sensor via the fiber. A possible embodiment would be for the fiber to carry to wavelengths, one is for charging the remote sensor and retro modulator via a miniature solar cell and the other wavelength would be retromodulated to facilitate the retrieving of the sensor information with "zero energy consumption.

MEMS Based retromodulation

MEMS devices are available in the market. A review of prior art modulation techniques appear in appendix 1, some of these techniques are MEMS based. A specific example, which is commercially available, is by Texas Instruments:

Digital Micromirror Device (DMDTM) by Texas Instruments.



The DMD light switch is fabricated by CMOS processes over conventional CMOS/SRAM
circuitry, and is the key to the Digital Light Processing (DLPTM) Technology developed by Texas Instruments.
Each pixel in a DMD device contains a square aluminum mirror, fabricated on hinges atop a static random access memory (SRAM) chip. The hinges allow the mirrors to tilt between two states, +10 degrees for "on" or -10 degrees for "off". When the mirrors are not operating, they sit in a "parked' position at 0 degrees. The light

reflected by "on" pixels is transmitted on through the projection system, whereas that from the "off' pixels must be absorbed or deflected away. Grey scale is achieved by modulating the incident light using a binary pulsewidth modulation scheme having 8 bits per color, producing 256 gray levels and 16.8 million different color combinations.

The DMD light switch pixel consists of a mirror that is rigidly connected to an underlying yoke. The dimensions of the mirrors have so far been fixed at 16μm square with centers spaced by 17 μm. . The yoke in turn is connected by two thin, mechanically compliant torsion hinges to support posts that are attached to the underlying substrate.

Electrostatic fields developed between the undeelying memory cell and the yoke and mirror cause rotation in the positive or negative direction. The rotation is limited by mechanical stops to +10 or -10 degrees.

At the heart of every DLP™ projection system is an optical semiconductor known as the **Digital Micromirror Device** , or DMD chip, which was invented by Dr. Larry Hornbeck of Texas Instruments in 1987.

A DMD panel's micromirrors are mounted on tiny hinges that enable them to tilt either toward the light source in a DLP™ projection system (ON) or away from it (OFF)-creating a light or dark pixel on the projection surface.

Digital Micromirror Devices (DMD)

DMDs, also called **digital light processing** (DLP), were developed by Texas Instruments. The DMD is a chip that has anywhere from 800 to more than 1 million tiny mirrors on it, depending upon the size of the array.

Each mirror rests on support hinges and electrodes.

The bit-streamed image code entering the semiconductor directs each mirror to switch on and off **up to several thousand times per second**. When a mirror is switched on more frequently than off, it reflects a light gray pixel; a mirror that's switched off more frequently reflects a darker gray pixel.

The present invention takes advantage of this DMD as a wide bandwidth retroreflector. One embodiment is described in Figure 14 showing a retromodulation device using the DMD. The light accumulated via lens 400 to hit a multi channel plate (MCP) 401, the light then emerges, maintaining the same angle and passes through a grid of holes 402 to hit the DMD 403. In A, the DMD is oriented in an angle (-10 degrees) that the light returns via the same holed in the grid and is retroreflected. In B, the DMD is positioned in a different angle, 404, such that the light reflected from the DMD is blocked on the grid. The light is thus not retroreflected.

By switching the position of the micro mirrors in the DMD, the light can be retromodulated. Very high bandwidth could be achieved as subsets of

mirrors could be used to generate gray level information and thus send multi bit data. By using, as an example, 4x4 mirrors a 4-bit channel is achieved increasing the bandwidth by x16.

Mutiple intrusion detectors

In another embodiment of the invention, the retromodulator is utilized in a security beam intended to detect intruders. Figure 7a demonstrates a typical intrusion detection set up where the energy is on one side and is retro reflected from the other side. This can be either a line detector or a "wall" detector. A beam 90 is sent toward a retroreflector 91. The retroreflected beam is detected by a photodiode 92. In order to avoid the possibility of fooling the protective beam by introducing a false retroreflector 93 into the beam, the retroreflector 94 of the current invention is modulated with a coded modulation, which may vary with time. The retroreflector energy consumption is low since energy is spent only on modulation and not on the generation of a carrier. Moreover, the retroreflector battery may be connected to a solar cell and be activated by the solar cell. The solar cell can also charge a battery for night operation or utilize the incoming beam 90 to charge the battery.

The intrusion detector may incorporate a wide-angle receiver with the capability of detecting a multitude of intruders. The transceiver may need to utilize, too high power levels if range is large. In that case, the present invention enables the use of small power levels as a result of the capability to emit a low continuous power for the detection of the presence of a retroreflector and increase the power lever once retroreflector is detected in order to identify whether the intruder is a friend or a foe with a larger communication bandwidth. The transceiver 96 is comprised of a multitude of Cassagrain transceivers 95 which emit a wide-angle beam. The concentric receiver is located on the back of the smaller convex mirror typical to the Cassagrain design. It must be realized that the current invention presents a combination of a retromodulator and a transceiver.

In another embodiment of the invention, it is also possible to filter the optical spectrum of the retromodulator, so that the retromodulator retroreflects one wavelength and not another wavelength. Moreover, the optical spectrum may be hopped from one wavelength to another in a fraction of a second. This can be achieved by coating the back mirror of the retromodulator with a spectrally narrow band material such as nano particles of specific size. Such particles produce specific reflective colors. It is also possible to electrically vary the wavelength of the reflecting coating, thereby changing the operating wavelength of the

retromodulator. This additional feature makes the retromodulator tamper free as time varying color-coding will secure that only the right pattern of colors will be retroreflected.

The use of solar cells instead of batteries can be applied to many other embodiments of the current invention including the use of the retromodulator sensor in households (such as temperature sensors in and outside the house).

Retromodulator integrated with a digital camera

In another embodiment of the invention, depicted in figure 8, an energy saving retromodulator is incorporated in a camera and enables the remote transmission of pictures without fast depletion of the camera batteries. A camera could be any commercial camera such as produced by companies like Nikon, Fujinon, Pentax etc. Current cameras 101 with a lens 102 store digital pictures created on a CCD array 103 in a flash memory card 104 with the use of a connection 105. The card 104 may be removed 106. The number of pictures stored in 104 may vary, very often between 16 to 100 pictures, depending on the size of the memory and the number of picture pixels, which in the current state of the art cameras vary from 0.3 – 6 mega -pixels.
According to the current invention, the pictures stored in 104 are fed to a retromodulator unit 108 via a connection 107. A transceiver 109, which emits a wide-angle beam, 110 serves to collect he camera pictures and save them for further printing. The total information may attain a storage volume of 20 Megabytes or 160 Megabits, for a 16 pictures card, since pictures are often compressed according to JPEG standard, with an average of approximately 1-2 Megabytes / frame. Assuming downloading of the information lasts 3 minutes (which is much shorter than the normal waiting time for delivering a card to a picture printers), results in a communication channel of 160/180 kilo bits / second which is smaller than 1 Megabits/seconds. The modulator should normally operate at a 1 Megabits/ sec rate. This can be easily achieved at a low cost, using of the shelf components, by splitting the modulator into 10 parallel channels, each channel operating at a 100 kbits/sec. This is achieved with state of the art liquid crystal devices. The discrimination between the channels can be achieved by spectral filtration of channels. Another aspect of the present invention is the ability to download the images via the glass window of the photo shop, even when the shop is closed.

In another embodiment of the same application, a transceiver is attached to a computer at home. The camera is placed any where in the room. The transceiver detects the presence of the camera and requests the camera to retro modulate its retromodulator and enable the download of the pictures. The process may take a few hours on an automatic basis. In that case, assuming downloading the information within 1 hour, the information bandwidth is 10-20 times slower than in the former case, which means a retromodulator bandwidth of 50 – 100 kbits/sec with a single channel.
It must be appreciated that transmitting the information in an active way from the camera, and not by retroreflection according to the present invention, would dekte the camera batteries very fast.

A multispectral transceiver

Figure 10 shows an embodiment of the current invention, which utilizes a multi spectral incandescent spot halogen lamp 500 used at home as a light source of the transceiver. The lamp is small enough compared to distances in the room and can be considered a spot lamp. Receivers 501 and 502 (as well as additional ones) are located on the periphery of the lamp. Each receiver is filtered to another spectral band. As a result, information on the retromodulator (not shown) may be spectrally multiplexed and each detector will receive the information related to one spectral band. There are many equivalent schemes, which will become obvious to a skilled electronic engineer, such as performing the filtration inside each detector.

Figure 11 shows an embodiment whereby a retromodulator which retroreflects electromagnetic waves in the mm wavelength region is located in a case which is transparent to mm waves and opaque to visible or infrared light. The retromodulator can be buried in sand or in snow or be located behind an opaque wall in a chemical plant.
The techniques of generation of mm wave electromagnetic radiation is well known in the art and is similar, for example, to the mm wavelength source produced by TeraView, UK.
The retromodulator can be made from an array of corner reflectors, each of 3-5 mm size. The array may incorporate 100 corners, with a total size of 50X50 mm. This produces a retroreflection with an angular divergence of wavelength / retro size ~ 1/50 = approximately 2-3 degrees.
Modulation can be performed by MEMS techniques, changing the perpendicularity of the corner cube.
In one embodiment the mm wave source comprises of a multitude of sources (such as Gunn diodes or mm wave lasers well known in prior art)

similar in general design to the multi source IR lamp previously described. A review of the state of the art is the SPIE publication:

Terahertz Active Direct Detection Imagers*

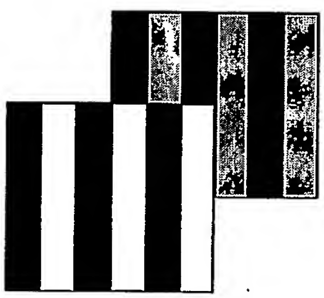
E. N. Grossman, A. Luukanen, A.J. Miller
Quantum Electrical Metrology Division, National Institute of Standards and Technology, Boulder, CO

Several embodiments are possible.

Some modulation techniques that are low power and miniature are:

Using a piezo actuator and a corner cube to alter the perpendicularity of the facets.
Using a Polyethylene lens (at 650 GHz) and an alternating grid and the focal zone.

The grid pattern in the focal plane of the "CAT EYE":



By moving the back layer in the lateral direction, either the reflecting or the non-reflecting stripes are positioned under the transparent section of the upper layer. The effect of that is modulation of the retro-reflected light. The advantage of this technique is that high range of energy modulation is achieved using relatively small motion, much smaller than the field of view of the device or its depth of focus, hence providing low energy consuming method of modulation.

<u>SNR calculations</u>

The SNR calculations are based on an initial literature review, including manufacturers of components for the relevant frequency range (such as Virginia

diodes) and on a few papers including the a/m. This paper quotes the following information:

In mm waves:
Quoting:

be true. Table 1 (courtesy T. Crowe, VDI Inc.) details the performance of a waveguide-coupled Schottky varactor double, operating at 70 GHz output frequency, with a fixed peak power input of 8 W.

Duty cycle	Output power at 70 GHz (W)	Efficiency (%)	$P_{out} * D^{1/2}$ (W)
CW	1.4 W	17.5	1.4
10 %	2.0 W	25	0.63
4 %	2.7 W	33.8	0.54
2 %	3.1 W	38.8	0.44

Table 1. Performance of a waveguide-coupled Schottky varactor (courtesy T. Crowe, VDI Inc.).

The output power is 1.4 W CW

As for detection: A value of 4 pW/Hz^½ is achievable in the MM waves.

In the 650 GHz range:

We can, based on the a/m reference, assume 3 mW power and 15 pW/ Hz^½. NEP.

Assumptions for the calculation in 95 GHz

Transmitter divergence – a = 15 degrees
Pout = 1.4 W
NEP = 4 pW/Hz^½
Distance – R = 200 meter
Detection aperture – Ad = 600 cm²
Retro aperture – Ar = 1 cm²
Link transmission Tr = 0.25
Bandwidth B = 10 Hz

Assumptions for the calculation in 650 GHz

Transmitter divergence – a = 2 degrees
Pout = 3 mW
NEP = 15 pW/Hz^½
Distance – R = 200 meter
Detection aperture – Ad = 800 cm²
Retro aperture – Ar = 1 cm²
Link transmission Tr = 0.2
Bandwidth B = 10 Hz

$SNR = Tr^2 \cdot Pout \cdot Ar \cdot Ad / (aR)^2 \cdot NEP \cdot B^{\wedge}½ \cdot (? / Ar^{\wedge}½)^2 \cdot R^2$

At 95 GHz – SNR = 3.93
At 650 GHz – SNR = 4.8

A related embodiment is shown in Fig 15 where mm or tera Hz radiation 410 is hitting a corner cube 411, the corner cube is designed to be in mechanical resonance with a piezoelectric material 412, attached to its backside. Upon triggering the piezomaterial with the driving signal 413, the corner cube 411 will resonate and hence will deform its planar sides. This will result in change in the retroreflection properties and hence the modulation. An ultrasonic drive frequency of typically 100 kHz will resonate the corner with dimensions suitable for the mm waves. Non-resonant embodiments are also part of the present invention.

Identification of moving people

In another embodiment of the invention, a tiny retromodulator (visible or mm vaves) is fixed on a person who should be promptly identified. Such a person could be a soccer player who is caught by a camera during the broadcasting of a soccer match. The transmitter is fixed on the camera utilized by the broadcasting team and transmits in a direction parallel to the camera viewing direction. There is an interest to immediately and automatically display the name of the soccer star so that the TV spectators know who is seen on the screen. By permanently modulating the retromodulator with the player name, the camera/transceiver system can automatically identify and display the name of the player. That technique is usefull also in broadcasting sport activities in Olympic games, or identify people in crowded places for security purposes.

Low power retro signaling device for bicycles / motorcycles and cars

The scenario of a bicycle at night on the side of the road with a flickering diode array is familiar to everyone. The high intensity flickering diodes are alerting the attention of the driver who thus notices the existence of a bicycle on the side of the road.

Another part of the invention involves the use of retromodulation signaling for bicycles to take advantage of the incoming car headlights as the source of energy.

The principle of operation is shown in Figure 12 where a low power, typically 1-2 Hz retromodulator is modulating the retroreflection via the lenselet array. Thus the bicycles will be visible from long distance when illuminated by the approaching car headlights.

To avoid blurring of the driver the divergence angle of the device could be monitored.
An ideal bicycles protection would thus comprise of an active and a passive device. The on time of the active device could be reduced thus further minimizing the energy consumption.

Retromodulated warning stripes on clothing

Road workers, working at night, are equipped with a shirt/coat with fluorescent, retroreflecting stripes. These stripes are intended to trigger the alert of an approaching vehicle. The present invention proposes a technique to retromodulate these stripes to be retroreflecting and non-retroreflecting periodically. The result would be flickering stripes which are much more effective to trigger attention. Furthermore if the retroreflection is done in the IR range it could be used as a Friend or Foe provision where a modulated stripe at a known pattern observed by a star light scope is an indication of a friend.
In order to maintain the stripe flexibility several designs are possible:

- Using the present stripe 304 with a light modulator such as a PDLC polymer (polymer dispersed liquid crystal) on top and a paper battery below. This is shown in figure 13 where the PDLC 300 is connected to the paper battery 301 via a standard battery press-able socket 302. A miniature flexible circuit 303 is modulating the transparency of the PDLC in a known pattern. The operation stops when detaching the connector.
  When the PDLC is transparent the stripes are retroreflecting, when it is translucent there is no retroreflection. The visual effect would thus be of flickering stripes.
- Other embodiments with a different order of the components are also possible to generate the modulation.

6. What is claimed is:

1. A method and apparatus for the sensing of a physical entity and communicating the information about the sensed entity to a remote station, said sensing method and apparatus incorporates a sensor subassembly which is integrated with an optical retromodulator, and a transceiver subassembly located at a distance, said transceiver incorporates a light beam transmitter and a mean to

detect and demodulate the light modulated and retroreflected by the retromodulator.

2. Said sensor as in 1 may sense any entities in the list of air pollution, toxic or hazardous chemicals in the air, toxic or hazardous chemicals in water, temperature, an image, biometric information, strain, pressure, liquid or gas leak.

3-39. Claims 3 to 39 are identical to the objectives 1- 39, mentioned above, respectively.

40. Said sensor as in 1 modulates the said retromodulator at any rate between 0.01 bits / sec to 10 Megabit /sec.
41. Said transceiver in 1 is located on the ground.
42. Said transceiver as in 1 is located on an airborne vehicle.
43. Size of said airborne vehicle as in 4 is between 4 meters and 1 mm.
44. The velocity of said airborne vehicle is between zero (balloon or smart dust or helicopter) and 1500 km/hour (as in a rocket).
45. Transceiver said in 1 is a multidirectional (broad angle) transceiver.
46. Multidirectional transceiver said in 8 consists of a multitude of segments; said segments may be of Cassagrain type transmitter with a receiver in front of said Cassagrain transmitter.
47. Radiation emitted from each section of transceiver said in 8 is eye safe.
48. Transceiver said in 1 continuously emits essentially low power radiation to detect retromodulator said in 1, and increases emitted power in order to detect information retromodulated by retromodulator said in 1 with high enough signal to noise ratio once retromodulator has been detected.
49. Transceiver said in 11 switches active detector once retromodulator is detected by another transceiver in the transceiver array.
50. Sensor as in 1 and retromodulator as in 1 are both located on air born vehicle (sensing is performed from an airborne vehicle and not from ground.).
51. Transceiver assembly on airborne vehicle or on ground communicates with a multitude of deployed sensors as in 1.
52. Transceiver light source is any in the list of LED or an array of LEDs, or a laser or an incoherent lamp.
53. Transmitter in transceiver as in 1 emits light at more than one spectral bands or lines, said retromodulator as in 1 spectrally multiplexes information by retromodulating some information at one spectral band and other information with another spectral band, said transmitter source may be any of light sources in the list of:

home use incandescent lamp, spot halogen lamp, spot high intensity metal halide lamp, multi spectral LED.

54. Airborne transceiver as in 5 is scanning the ground in order to compensate for airborne vehicle movement and keep the retromodulator in the transceiver long enough time to enable the use of a smaller information bandwidth.
55. Transceiver said in 1 incorporates a fiber or a fiber bundle; said fiber or fiber bundle is brought at a close distance of a sensor and retromodulator.
56. A retromodulator integrated with a digital camera.
57. Said digital camera in 19 stores a traffic picture, analyzes the traffic picture and later on retroreflects picture into a transceiver station according to a criteria stored in the digital camera or in electronic device attached to the camera.
58. Said digital camera in 19 is on a security fence, said camera takes an image at specific time intervals and retroreflects the image.
59. Said digital camera as in 19 is located on an airborne vehicle.
60. Camera said in 22 has a protective mean against hazardous materials and camera is located in a hard to access area.
61. Said camera as in 19 is a commercial consumer camera.
62. Said camera is on a smart biometric identification device (or card), said camera takes pictures of the smart card holder, said camera incorporates a mean to analyze the biometric information collected by said camera, said smart card already stores biometric information on card holder, said smart card incorporates a retromodulator for the retromodulation of the car holder biometric information to a transceiver for comparison of stored biometric information to currently imaged biometric information..
63. Said smart identification card incorporates both a camera and or a microphone and said identification is based on either one or both biometric image visual data and voice analysis.
64. System which comprises of a camera located in the entrance of a secured gate (such as bus entrance, air port gate), said camera can take a picture of an identification smart card holder and analyze biometric information acquired from said picture, said identification smart card incorporates a memory, said memory pre stores biometric information on the card holder, said card also incorporates a retromodulator which can be modulated with the pre stored biometric information, and said system also incorporates a transceiver (located on the entrance or gate), said transceiver is capable of illuminating the card and retrieve the biometric information from the card , and said system also incorporates a

computer which is capable of comparing the biometric information acquired by the camera to the pre stored biometric information.

65.System as in 27, whereby said camera is replaced by a microphone, or, whereby both a camera and a microphone are used.

66.A system for the detection of leaks in sewage pipes, said system incorporates a fiber transceiver and retromodulator sensors are located on the walls of the pipes.

67.A pollution monitoring system, said system comprises of a miniature Helium or vacuum balloon, said balloon is floating in an atmospheric region suspected of being polluted, said balloon incorporates a retromodulator, said retromodulator is connected to a pollutant sensor, said system also incorporates a transceiver.

68.System as in 30, said modulator modulates at a frequency, which enables the discrimination between ambient light and light emerging from the pollution sensor.

69.Pollution monitoring system whereby a multitude of balloons as in 30 are released to the atmosphere.

70.An optical retromodulator, which incorporates active nano material such as solid-state quantum dots.

70. Use of embedded active nano material as a light source.

71.Use of embedded active nano material as a light modulator.

72.A nano material based light modulator controlled by a local light source.

73.A nano material based light modulator controlled by a local electronic generator.

74.An optical component embedded in a polymer substrate.

75.An optical component embedded in a glass substrate.

76.An optical component embedded in an optical fiber.

77. An optical retromodulator, which incorporates a liquid crystal.

78.A friend or foe (FOF) identification device, said FOF incorporate a sensor which senses the device holder (as opposed to pre stored data), said device also stores pre stored data, said device incorporates a retromodulator as in 1 and is responding to light emitted by transceiver as in 1.

79.FOF device, said sensor is any one of the list of microphone, camera, skin sensor, biometric sensor.

80.Any of claims 1-79, said electromagnetic wave is in the millimeter waves region.

81.Any of claims 1-79, said wave is an ultrasonic wave.

82.A camera which incorporates a transceiver and a retromodulator attached to a person such as a soccer player, said retromodulator being modulated with information which identifies said person,

said camera or transceiver connected to a computer, said computer enables to write the name of said person on the display unit of said camera in real time, said retromodulator operating at any wavelength in the visible, infrared or millimeter wave region of the spectrum.

83. A bicycle retromodulator-signaling device for alerting the attention of approaching drivers to their existence.
84. A motorcycle retromodulator-signaling device for alerting the attention of approaching drivers to their existence.
85. A pedestrian retromodulator-signaling device for alerting the attention of approaching drivers to their existence.
86. Retromudulated flickering stripes on clothing.
87. Retromudulated flickering stripes on hats and or helmets.
88. Retromudulated flickering stripes using a paper battery as the energy source.
89. Flexible retromudulated flickering stripes.
90. Wide bandwidth retromodulator using DMDs
91. Wide bandwidth retromodulator using DMDs in conjunction with an MCP.
92. Wide bandwidth retromodulator using DMDs inn clusters of elements to achieve multi bit operation and wider bandwidth.
93. A corner cube retromodulator using a piezo element as the modulating mean.
94. Setting the ultrasonic resonance compatible with the MM wavelength for maximal modulation efficiency.
95. Using s corner cube to retromodulate ultrasonic radiation.
96. Using a set of reflective and transparent stripes moving in respect to one another in a focal zone of a lens to retromodulate mm waves.

Annex 1

Modulated Retroreflector - Patent Search Report.

Keywords: Modulated Retroreflector, Active Retroreflector, Retromodulator, Light Crystal Shutter, Optical Smart Card, Remote Identification System.

Sources: www.uspto.gov, esp@cenet.

1. United States Patent **6,507,441**
Eisenberg , et al. **January 14, 2003**

Directed reflectors and systems utilizing same

Abstract
A wide angle directed reflector is disclosed. The directed reflector includes a lenticular layer including at least one array of lenslets, each of which having a focal length. The directed reflector further includes a reflective layer which is disposed relative to the lenticular layer. The lenticular layer and the reflective layer are constructed, designed and relatively disposed such that light incident at an angle of incidence on the lenticular layer is reflected by the reflective layer and redirected through the lenticular layer at a substantially constant angle relative to the angle of incidence.

2. United States Patent **6,233,088**
Roberson , et al. **May 15, 2001**

Methods for modulating a radiation signal

Abstract
A reflector having a mechanically deformable portion of at least one reflective surface is disclosed. By deforming the portion of the reflective surface, discontinuity is introduced in that portion of the reflective surface. The discontinuity in the reflective surface scatters incident radiation signals so as to cause attenuation in the reflected signal. By selectively deforming the portion of the reflective surface, the reflected signal can be modulated to encode data thereon. The mechanically deformable portion of the reflective surface preferably comprises plates integrally formed therein.

3. U.S.Patent No. 6, 137, 623

Patent number:	US6137623
Publication date:	2000-10-24
Inventor:	RINNE GLENN A (US); DEANE PHILIP A (US); MARKUS KAREN W (US); ROBERSON MARK W (US)
Applicant:	MCNC (US)

Abstract of **US6137623**

A reflector having a mechanically deformable portion of at least one reflective surface is discbsed. By deforming the portion of the reflective surface, discontinuity is introduced in that portion of the reflective surface. The discontinuity in the reflective surface scatters incident radiation signals so as to cause attenuation in the reflected signal. By selectively deforming the portion of the reflective surface, the reflected signal can be modulated to encode data thereon. The mechanically deformable portion of the reflective surface preferably comprises plates integrally formed therein.

4. United States Patent **6,154,299**

Gilbreath , et al. **November 28, 2000**

Modulating retroreflector using multiple quantum well technology

Abstract

A system for remote optical communications includes a base station and a remote station. The remote station includes a retroreflector, a multiple quantum well modulator (MQW), and drive circuitry that drives the MQW. A base station transmitter sends an interrogating light beam to the MQW, which modulates the light beam based on the information in the electrical signal from the drive circuitry. The retroreflector reflects the modulated light beam to the base station for detection by a receiver.

5. United States Patent **5,909,299**

Sheldon, Jr. , et al. **June 1, 1999**

Microsatellite system for high-volume orbital telemetry

Abstract

Detailed mapping of the magnetosphere is made possible by deploying hundreds of attitude-impervious microsatellites, in the form of small corner reflectors with piezoelectric mirror surfaces, from a single mother sate llite at spacings of as little as 1 km in equatorial and elliptical orbits. The microsatellites carry magnetosensors whose output is transmitted to a ground station by modulating the reflection of a laser beam transmitted to the microsatellite by the ground station. Various refinements of the laser data link are also disclosed.

6. United States Patent **4,983,021**

Fergason **January 8, 1991**

Modulated retroreflector system

Abstract

A reflector system including a reflector for reflecting incident electromagnetic energy, a shutter for controlling at least one of electromagnetic energy incident on and electromagnetic energy reflected by the retroreflector, a controller for controlling the shutter to control such incident or reflected electromagnetic energy, and a coding or modulating device for causing the controller to modulate such energy according to a prescribed code. The reflector system may be used in a closed communications system and/or in a system for seeking, locating and/or identifying an object.

7. United States Patent **4,889,409**

Atcheson **December 26, 1989**

Hemispherical retroreflector

Abstract

A retroreflector comprising two hemispheres of differing radii. The spherical surface of the first hemisphere is disposed towards a radiation source and the second hemisphere is provided with a reflective coating on its spherical surface. Means for modulating radiation from the retroreflector can be utilized within the retroreflector. In addition, smaller concentric inner hemispheres or a concentric inner sphere may be provided to correct chromatic and spherical aberrations produced by the retroreflector. Advantages obtainable with the disclosed retroreflector include consistent return efficiency over a large field of regard and consistent return efficiency over a wide spectral region.

8. U.S. Patent No. 4,784,448

Patent number:	US4784448
Publication date:	1988-11-15
Inventor:	BORN GUNTHARD (DE); SEPP GUNTER (DE)
Applicant:	MESSERSCHMITT BOELKOW BLOHM (DE)

Abstract of **US4784448**

A retromodulator in the form of a triple mirror with electromechanical transducer elements for planar deformation by which incident light radiation is retroflected in modulated form. At least one face of the retromodulator is formed as an oscillatory diaphragm which is excited to natural oscillations by the transducer elements. In a preferred form of realization, the oscillatory diaphragm comprises a piezoelectric foil, on whose inner side a reflecting layer is applied and on whose outer side electrodes are applied to which the modulation signal is applied.

9. U.S. Patent No. 4,731,879

Patent number:	US4731879

Publication date: 1988-03-15

Inventor: HARASIM ANTON (DE); SEPP GUNTHER (DE)

Applicant: MESSERSCHMITT BOELKOW BLOHM (DE)

Abstract of **US4731879**

The present remote data monitoring system employs a laser and a modulated retroreflector for the remote data monitoring of hard to access spaces, targets etc., in combination with an arrangement for a simultaneous friend-or-foe identification, and in combination with devices for the protection against detection and against interrogation of a friend by an enemy laser. In this system, a liquid crystal modulator of special construction depending on the purpose and structure of the system, is arranged in front of a retroreflector and modulated by the respective information. The information is interrogated by a spatially distant laser station by directing a laser beam onto the retromodulator, whereby the information is retroreflected and simultaneously modulated.

10. United States Patent *4,540,243*

Fergason *** September 10, 1985**

Method and apparatus for converting phase-modulated light to amplitude-modulated light and communication method and apparatus employing the same

Abstract

A light modulator for generating a beam of amplitude-modulated light including a source of polarized light, at least one and preferably two liquid crystal cells having a thin layer of nematic liquid crystals of positive dielectric anisotropy through which the polarized light is directed to produce a beam of light having a phase shift corresponding to a modulating electrical signal which is applied to each of the liquid crystal cells. The liquid crystal cells in addition have a continuing electrical bias applied across the layers in order to achieve the rapid response times necessary to achieve phase modulation of the polarized light. The resulting phase-modulated light is converted in a linear polarizer to amplitude-modulated light corresponding to the modulating electrical signal. The amplitude-modulated light is detected in a suitable light detector which generates an electrical signal corresponding to the modulating electrical signal. The linear polarizer may be oriented with either the transmitter or the receiver. A communication system involving a transmitting modulator and a receiving demodulator transmits communication through light either as phase-modulated light or as amplitude-modulated light.

11. United States Patent *4,385,806*

Fergason **May 31, 1983**

Liquid crystal display with improved angle of view and response times

Abstract

A nematic liquid crystal light shutter with improved angle of view by the incorporation of retardation plate means disposed in front of the liquid crystal cell to compensate for the off-axis performance of the device due to the birefringent nature of the liquid crystal material. When the transparent plates of the liquid crystal display are rubbed or otherwise aligned at right angles to each other to effect a twisted-nematic structure, two retardation plates are employed, the net retardation of each being less than or equal to the net retardation of the liquid crystal material itself. On the other hand, when the plates are rubbed or otherwise aligned parallel to each other, three retardation plates can be employed. The retardation plates can be incorporated into the front polarizer which is to be used on the display. Also disclosed is a liquid crystal display device having an exceedingly high speed of response.

12. DE19652920

Patent number:	DE19652920
Publication date:	1998-04-30
Inventor:	WARM BERNDT DR ING (DE)
Applicant:	DIEHL GMBH & CO (DE)

Abstract of **DE19652920**

The passive response device (11) has a modulatable reflector (24) for the interrogation beam (14) of an optronic friend or foe identification device. A modulator (23) is provided for time controlled temporary lifting of the retroreflection operation of a triple reflector (13). The reflector is made up of a combination of prisms or mirrors as reflectors (24). An optical change in the total reflection may be provided at the reflector (24). A mechanical change of the angle of reflection may be provided at one of the reflectors (24). The modulator may affect the retroreflection with linear actuators acting on the reflector (24).

13. GB2109121

Patent number:	GB2109121
Publication date:	1983-05-25
Inventor:	HEEKS JOHN STUART
Applicant:	STANDARD TELEPHONES CABLES LTD

Abstract of **GB2109121**

An optical retromodulator comprises an optical corner reflector 1 (depicted symbolically) in front of which is placed an electro-optical phase change plate 2. Signals from a modulator 3 effect changes in the optical path length of the plate 2. Light incident on the corner reflector passes through the phase change plate twice. Thus for an

effective phase change of 90 DEG in the plate the emergent light is subjected to a 180 DEG phase change and the modulated light is reflected back to its source.

14.Method for producing nematic liquid crystal devices

Patent number:	EP1369739
Publication date:	2003-12-10
Inventor:	FAGET LUC (FR); DOZOV IVAN N (FR); JACQUIER SEBASTIEN (FR); LAMARQUE-FORGET SANDRINE (FR)
Applicant:	NEMOPTIC (FR)

Abstract of **EP1369739**

A method of producing nematic liquid crystal devices in which a weak zenithal anchorage energy of the liquid crystal is obtained on at least one of its confining plates by depositing onto a substrate a polymer, copolymer or terpolymer deriving from poly(vinyl chloride-co-vinylalkylether) or poly(vinyl chloride-co-vinyl aryl ether), stabilizing the deposit and defining a azimuthal orientation of the deposit which induces a controlled azimuthal anchorage of the liquid crystal. An Independent claim is included for a bistable nematic liquid crystal device using at least one weak zenithal energy anchorage layer obtained by the claimed method, the layer being deposited on a transparent or reflecting electrode.

15. Bistable nematic liquid crystal device

Patent number:	GB2330214
Publication date:	1999-04-14
Inventor:	BRYAN-BROWN GUY PETER; SAGE IAN CHARLES; WOOD EMMA LOUISE
Applicant:	SECR DEFENCE (GB)

Abstract of **GB2330214**

A bistable nematic liquid crystal device comprises a layer of a nematic or long pitch cholesteric material contained between two cells walls. One or both walls are surface treated to provide two stable alignment directions into which liquid crystal molecules may switch under the influence of an applied electric field. This surface treatment also provides pretilt to the molecules and the pretilt angle may be different for the two alignment directions. The invention improves the switching by removing inelastic azimuthal memory anchoring energy and reducing azimuthal and zenithal anchoring energy of liquid crystal molecules at the cell walls without substantially changing molecular pretilt angles. The reduction in anchoring energy may be by a treatment to the cell walls or by an additive in the liquid crystal

material. The treatment and additive may be an oligomer or short chain polymer applied to the wall prior to assembly in a cell, or as an up to 5% additive. The oligomer may be UV cured Norland N65 or $-[S(CH_2)_6SCH_2CH_2O(CH_2)_6OCH_2CH_2]_n-$, HDVE (Hexane - 1,6-diol di(vinyl ether), BVE (Butyl vinyl ether), EGTG (Ethylene glycol bis(thioglycollate)), NDT (Nonane-1,9-dithiol).

Annex 2

Light modulators applicable for retroreflection.

Keywords: Ferroelectric Liquid Crystal (FLC) Spatial Light Modulator (SLM), ZBD Reflective and Transmissive Display, Multiple Quantum Wells (MQW) Modulators, Liquid Crystal On Silicon (LCOS) Microdisplay, Micro-Electromechanical System (MEMS), Optical Retro Modulator, Retro-Reflective Light Modulator, Modulating Retro Reflectors, Passive Optical Modulation, LC Retro Modulator, LC SLM, LC Switches, Liquid Crystal Bistable Display, Two-Dimensional Electro-Optical modulator, Digital Mirror Device (DMD), Electro-Optic Beam Steering Device, Optical Shutter.

Major worldwide developments in bistable LCD:
• Surface bistable nematic
• Cholesterics
• Ferroelectrics
• Flexoelectrics nematics
• Flexoelectrics with surface grating (ZBD)
• Bistable nematic (Nemoptic)

I. Nematic liquid crystals.

1. Zenithal Bistable Device (ZBD)
ZBD Displays Limited

1.1 ZENITHAL BISTABLE DISPLAYS
J. C. Jones, P. Brett, G. P. Bryan-Brown, A. Graham, and E. L. Wood
ZBD Displays Ltd.,
Malvern Hills Science Park, Malvern, Worcs., WR14 3SZ, UK.
jcjones@zbddisplays.com , www.zbddisplays.com

ZBD relies on grating alignment of a nematic liquid crystal to produce two stable states. This leads to a number of attractive features, including low voltage operation, excellent optical properties and image retention, even when subjected to mechanical shock. Grating alignment layers are ideal for fabrication on plastic substrates, which then allows complex images to be displayed on devices with manufacturing tolerances similar to those of the conventional twisted nematic displays used in watches. Typical voltages required were 24V strobe (VS) and 4V data (Vd), although significantly lower voltages have been achieved in test cells. **This leads to an energy requirement for a single image update of less than 4μJ.** If the image requires constant updating the power consumption is about five times greater than that of an STN panel (due to the higher capacitance and addressing waveform frequency).

Size	2cm × 2cm
Complexity	90 × 83
Addressing	$24V_S \pm 4V_D$
Contrast	Pixel: 40 : 1 Panel: 15 : 1
Reflectivity	150% that of commercial STN
Line Address Time	100μs
Frame time	40ms
Update energy	4 μJ
AA battery life at 1Hz update (including driver power)	≈ 1000 hour
Image storage	≻ 2 years

Performance of ZBD™ Demonstrator.

Line address times of 40 μs has been achieved with 35V pulses. This need not be too costly in terms of power consumption which is dominated by the data voltage through terms in Vd 2/t (where t is the line address time). Multiplexing data as low as 2V is possible, allowing exceptionally low power even for images with continuous update, although the addressing window is then narrowed.

DISPLAY REQUIREMENTS FOR PORTABLE PRODUCTS

The growth in use of portable electronic devices has been substantial over the past decade, driven largely by the mobile telecommunications and personal digital assistant markets. Coupled with this growth has been an increasing demand for higher levels of displayed information, without a concomitant increase in display power budget. The usual choice for such applications is the Supertwist Nematic (STN) Liquid Crystal Display, due to its low cost and reasonable degree of complexity. **The type of reflective mode display presently used in mobile phones has a typical power consumption of about 0.15mW (for a 1.7" diagonal (9 cm²), 60×24 pixel STN).** The power increases with higher levels of complexity and display size; for example, a 4" diagonal 320×200 STN typically consumes about 3mW. This relationship between power and complexity proves restrictive for products such as the electronic book, where battery life is limited to several hours. In the near future, yet greater complexity will be required in products that combine the functions of the mobile phone, palm-top computer and electronic book. Display power will be a major issue for such applications.

At present, much research effort is dedicated for display products that provide the attractive appearance and high degree of complexity, whilst minimizing power consumption. Recently [1], highly reflective LCDs have begun to be used in portable

products (eg electronic games). These combine thin film transistor (TFT) to achieve the high levels of complexity, with a carefully designed micro-relief internal reflector to provide efficient usage of the ambient light. This type of device is sufficiently reflective to allow full colour operation using conventional colour filters. However, even for a 4" diagonal display the power consumption can be as high as 50mW.

1.2 Zenithal Bistable Device (ZBD) Suitable for Portable Applications

E.L. Woodl, G.P. Bryan-Brown, P. Brett, A. Graham, J.C. Jones, and J.R. Hughes
DERA Malvern, St. Andrews Road, Malvern, Worcestershire WR14 3PS, UK.

Reflective and Transmissive Displays.

In order to show the compatibility between the ZBD and a range of portable products, the display size and resolution were chosen to be approximately the same as a mobile phone or pager display. The display area is 2x2cm and it contains 83x90 pixels. Multiplexing studies of test cells however suggest that these devices may be driven with line-address times which are simply double the selection pulse width.

Table 1: Minimum switching voltages for transmissive display

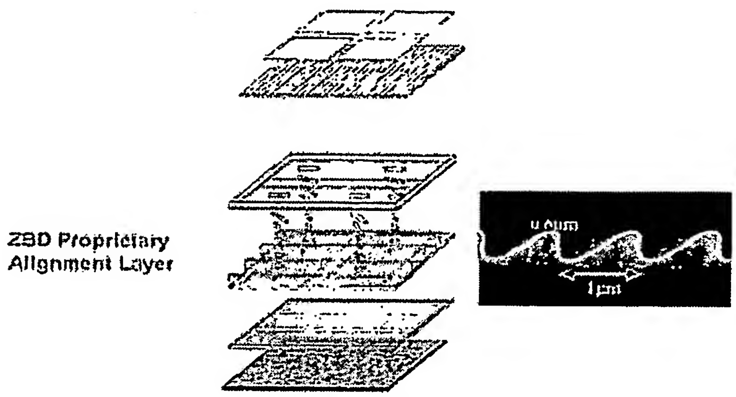
Slot Width (μs)	V_D (V)	V_S (V)
38	7.1	21.7
63	5.2	17.9
125	4.1	14.3
250	3.2	12.1
500	3.0	10.9

There was a very high normal incidence contrast ratio of 130:1 in ZBD Transmissive Display.

There was observed a photopic contrast ratio of 43:1 at normal incidence in ZBD Reflective Display

The zenithal bi-stable display uses a simple micro-structured grating surface to control the alignment of the liquid crystal molecules. There are two stable orientations for the molecules, black and white.

ZBD Grating Layer



ZBD achieves bistability using a grating structure with a homeotropic anchoring condition. Typically two states exist which have different surface pretilts. In one state the director points along the normal to the grating substrate (high-tilt), whilst in the other state, a lower surface tilt is realized which is dependent on the topology of the grating (low-tilt).
The zenithal bi-stable display is manufactured using a method often used for producing surface relief structures, from holographic wrapping paper to CD and DVD disks. It uses a master to stamp the required profile into a deformable material, thereby producing a perfect replica. ZBD is the first company to apply this simple technology successfully to the inner surfaces of LCDs.

The higher contrast (over 25:1), reflectivity (36%) and wide viewing angle (120? horizontal and 90? vertical for contrast ratios over 10:1) of a zenithal bi-stable display is closer to the performance of a high-price thin film transistor (TFT) display thana traditional low cost Supertwist Nematic display. Furthermore, it has the added benefits of ultra-low power and image storage. The image is even retained after severe mechanical shock, even without power.

The zenithal bi-stable display is the only passively addressed technology to rival active matrix LCD displays, offering equal performance, lower power and image storage at roughly half the cost. In addition, **the zenithal bi-stable display has the widest temperature range at -20°C to 80°C, the fastest update speeds at 2,500 lines per second and lowest operating voltages at 5V of all bi-stable technologies.**

The zenithal bi-stable display available for commercial supply during the first half of 2004 as a result of its collaborative development work with Varitronix Limited ("Varitronix"), one of the world's leading manufacturers of passive matrix liquid crystal displays.

2. NEMOPTIC

NEMOPTIC has a key competitive advantage with the very innovative Bistable Nematic (*BiNem®*) LCD technology. *BiNem®* technology is the next generation of LCD technology, which is becoming the new standard.

2.1 The BiNem® technology

Alain Boissier, President and CEO of NEMOPTIC
1, rue Guynemer, 78640 Magny les Hameaux France

Basics of the BiNem® technology
BiNem® stands for a new generation of nematic LCD technology. The BiNem® technology is
a passive bistable nematic technology.
BiNem® display modules only require power when it is needed to change the image content
on the display. Once the image is written, it will remain indefinitely without consuming any additional power.

Plastic substrates

Within the scope of two European contracts (CARBINE and FORMAT), NEMOPTIC has developed a *BiNem®* technology compatible with flexible plastic substrates in collaboration with smart card integrators (Gemplus, Oberthur Card System, ASK)..The purpose is to integrate flexible bistable displays into new smart cards for emerging applications such as electronic purses, transport ticketing or multi-purpose smart cards.

Prototype of a Flexible *BiNem®* display

Acknowledgments
The author would like to thank all his colleagues from Nemoptic and from **ORSAY University** for their contribution at all stages of the technology development.
The author also thanks Nemoptic licensees, **Tecdis in Italy and Picvue in Taiwan**, for their contribution to set up the BiNem. manufacturing process for mass production.

2.2 Fast Bistable Nematic Display Using Monostable Surface Switching

Ph. Martinot-Lagarde, I. Dozov, E. Polossat, M. Giocondo, I. Lelidis, G. Durand

Abstract:
We present a novel surface-controlled bistable nematic liquid crystal display. This black and white device uses simple monostable anchorings and is controlled by short electric pulses. **Writing and erasing is achieved by 30 µs pulses at driving voltage U=24 volt.**

2.3 Ultra low power bright reflective displays using BiNem. technology fabricated by standard manufacturing equipment

Cecile Joubert, Jacques Angele, Alain Boissier, Patrice Davi, Ivan Dozov, Thierry Elbhar, Bertrand Pecout, Daniel Stoenescu, Romain Vercelletto

Nemoptic, 1 rue Guynemer, Parc du Merantais, 78114 Magny les Hameaux, France
Philippe Martinot-Lagarde
Laboratoire de Physique des Solides, Université Paris Sud, 91405 ORSAY, France

Power consumption considerations.

In this section compare the BiNem. power consumption with that of standard STN . We assume the drivers (pixel driving voltage), the ITO and the pixel surface identical for both technologies. The power consumption P of the display can be written as :
$P \propto f C V_p^2$
with f pixel waveform frequency, Vp pixel driving voltage, C total capacitance of the display.
The capacitance of the display is directly proportional to the equivalent pixel capacitance :
$C = e0\ eR\ S/d$
with e0 vacuum permitivity , eR relative permitivity of the liquid crystal, S pixel surface and d cell gap. For STN, typical values are eR = 10 and d = 4,5 µm. For BiNem. , typical values are eR = 20 and d = 2 µm. Thus the equivalent capacitance of a BiNem. display is multiplied by 4 compared to that of a STN display.
However STN displays have to be addressed with a frequency of around 60 Hz to avoid the flicker.

	PDA	E-BOOK
Display technology	Bistable Nematic *BiNem*® LCD	
Optical mode	Pure reflective 2 polarizers	
Resolution	160 x 160	640 x 480
Pixel pitch	0.34 x 0.34 mm^2	0.2 x 0.2 mm^2
Reflectance	> 30 %	> 30 %
White coordinates	(0.32,0.34)	(0.32,0.34)
Contrast ratio	> 10	> 10
Viewing angle CR>4	Cone 55°	Cone 55°
Row voltage	±15 V	±15 V
Column voltage (data)	±2 V	±2 V

Table 2 : Characteristics of BiNem® prototypes

3. **Liquid Crystal on Silicon (LCOS) Microdisplay.**

1. MicroDisplay
MD1280P4 E-WX 1280 × 768 LCOS,
V0.1 dev 10/27/03

OVERVIEW
The MD l280P4 E-WX device is a high-resolution Liquid Crystal on Silicon (LCOS) microdisplay optimized for high performance single panel, dual-panel and triple panel projection applications. The MD1280P4 boasts a high contrast ratio, high brightness, and a very fast LC switching time. This display has been designed for optical engine architectures that require very high refresh rates and 24-bit color. Both field sequential and scrolling color management techniques are supported.

TYPICAL APPLICATIONS
• Rear Projection Televisions
• Front Projectors

KEY SPECIFICATIONS
Diagonal: 21.1 mm
Resolution: 1296 × 784 Full Array
Display type: Gray-scale active-matrix liquid-crystal-on-silicon CMOS backplane
Display mod: Reflective, normally white, **nematic liquid-crystal material**
Grayscale accuracy: 24 bits (8 bits per color)
Signal Interface: MicroDisplay PixelPort 2C(MPP2C)
Field rate: 60 Hz – **540 Hz**
Photopic Reflectivity: ~ 63% over F# = 2.8 (full visible spectrum)
Contrast Ratio: ~ 600:1 over F# = 2.8 (full visible spectrum, with ContrastCouplerTM)
Liquid Crystal Switching Speed: 0.15ms 90%-10% (bright to dark) @ 50C,
1.0ms 10%-90% (dark to bright) @ 50C

Coating: Anti-reflection coated, R < 0.3% between 420 – 680 nm
Pixel-mirror fill factor: 90.4%
Pixel pitch: 13.95μm * 13.95 μm
Dimensions of pixel array: 17.86 mm x 11.16 mm
Dimensions of display cell: 21.86 mm x 16.49. mm
Supply voltage: 12.0 V Analog, 3.3 V Digital
Power Consumption: <400 mW @ 540 fields/sec
Storage temperature 5°C to 60°C

II. Ferro -Electric Liquid Crystal (FLC) Spatial Light Modulators (SLM) and Shutters.

1. Optical Comparator Based on an FLC over Silicon SLM

T.D. Wilkinson, N. New and W.A. Crossland

Cambridge University Engineering Department

A FLC SLM is constructed as a thin layer (around 2μm) of Smectic C^* FLC sandwiched between two transparent electrode arrays. The FLC molecules are aligned parallel to the electrodes by alignment layers. The electric field is applied via a pixellated pattern of ITO (Indium Tin Oxide) on the glass. The rear glass wall can be replaced by a silicon VLSI die to make a silicon backplane SLM. The SLM is now a reflective modulator with the aluminium from the metal 2 of the VLSI process acting as a mirror[3,4]. Circuitry on the backplane can be used to address the FLC pixels as either a dynamic random access (DRAM) pixel[3,4] or as static RAM (SRAM)[10].

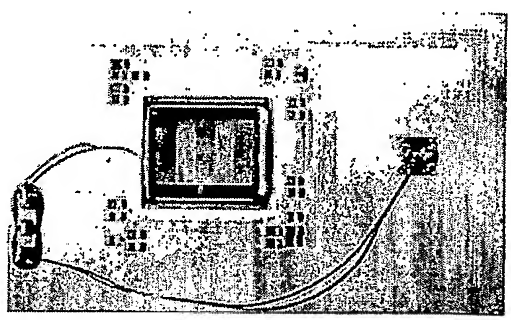


Figure 2 A: 320x240 pixel **silicon backplane FLC SLM.**

The silicon backplane SLM is very important to the development of non-display applications as it allows large arrays of very small pixels to be built on a silicon wafer capable of high-speed addressing speeds. Compared with line-at-a-time multiplexed SLMs, these silicon backplane SLMs allow a full frame of pixels to be addressed in one liquid crystal response period (as opposed to one row), hence they can be K times faster, where K is the number of rows. **A 320x240 array of 37μm**

pixels (11.8x8.9 mm aperture) capable of displaying 44,000 frames per second is shown in Figure 2[11].

2. BOULDER NONLINEAR SYSTEMS, INC.

450 courtney Way, Unit 107
Lafayette, CO 80026
(303) 604-0077

2.1 Optical Code Division Multiple Access systems in High-Speed telecommunications.

PI: Dr. Ping Wang
UNIV. OF COLORADO Campus Box 525 Boulder, CO 80308 (303) 492-3330

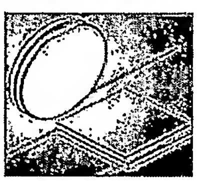
Abstract: BNS proposes a spectral optical code division multiple access (OCDMA) system with bipolar code capability for use in ultra-high-speed communication applications. The proposed technology integrates multiple encoders for different users into a compact central unit, reducing overall system costs. A two-dimensional electro-optical modulator, a digital mirror device (DMD), or a liquid crystal (LC) spatial light modulator (SLM) is used to spatially modulate the spectrum of the light source which carries user signals. The use of a two-dimensional array modulator enables parallel encoding to multiple user signals, with certain rows dedicated to each user. The advantage of the proposed system is that the spectral codes are re-configurable. Each subscriber is able to communicate with all other subscribers. With its spectral bipolar code capability, the system can reject multiple access interference. The system can be made very compact even with large numbers of subscribers when large format 2-D SLMs and DMDs are used. Due to its programmability and two-dimensional operation in the optical domain, the system is suitable for implementing optically transparent routings in an ultra-fast Asynchronous Transfer Mode (ATM) switch.

Boulder Nonlinear Systems, Inc. Ferro-Electric Liquid Crystal (FLC) And Nematic Liquid Crystal (NLC) shutters offer superior light control for applications demanding high extinction ratio and/or high-speed operation. The devices can be used to create custom displays, control the output of lasers, provide stereoscopic vision, or as a camera shutter control in machine vision applications to name only a few possible applications.

The FLC shutters have very fast switching times, on the order of 5-150μsec. The shutter can be powered by a zero mean 5v AC signal, larger amplitudes can result in faster switching times. Lower amplitudes will yield a gray-level response. Typical FLC shutters must be used at a 50% duty cycle, however for some applications custom multi-layer shutters can be designed to overcome this duty cycle limitation. The shutters are typically delivered with cross polarizers mounted on either side of the cell to provide a linearly polarized output. **The extinction ratios achieved can be as high as 20000:1 (-43 dB) for a monochromatic light source** or 500:1 (-27 dB) with a broadband light source. The shutters provide an open-state transmission of as high as 48% for an unpolarized monochromatic light source and 30% for an unpolarized broadband light source.

Device Specification	FLC Shutter	ZTN Shutter	TN Shutter
Number of Pixels:	1 to 256	1 to 256	1 to 256
Clear Aperture:	1-mm to 150-mm	1-mm to 150-mm	1-mm to 150-mm
Pixel Pitch:	5-µm to 150-mm	5-µm to 150-mm	5-µm to 150-mm
Extinction Ratio:	Up to 500:1 (-27dB)	Up to 1,000:1 (-30dB)	Up to 20,000:1 (-43dB)
Closed Shutter Transmission:	<0.096%	<0.048%	<0.0024%
Open Shutter Transmission:	20% to 48% of unpolarized light 40% to 96% of polarized light	20% to 48% of unpolarized light 40% to 96% of polarized light	20% to 48% of unpolarized light 40% to 96% of polarized light
Operating Wavelength Range:	Maximum bandwidth of approximately 300nm anywhere from 300nm to 5µm	Maximum bandwidth of approximately 300nm anywhere from 300nm to 5µm	Maximum bandwidth of approximately 300nm anywhere from 300nm to 5µm
Optical Response Time (10%-90%)	5µs to 150µs	Closing Time: 100µs to 2ms Opening Time: 500µs to 20ms	Closing Time: 100µs to 15ms Opening Time: 2ms to 150ms
Duty Cycle:	50% for single-layer device 0% to 100% for multi-layer device	0% to 100%	0% to 100%
Operating Temperature Range:	+20°C to +30°C[1]	+20°C to +30°C[1]	-20°C to +90°C
Storage Temperature Range:	-10°C to +60°C	-40°C to +90°C	-40°C to +90°C

2.2 MS Series OEM Optical Shutters.



Clear Aperture	5-95 mm
Wavelength Range	425-675 nm
Pixel Count	1-256
Pixel Pitch	5 µm (minimum)

Contrast Ratio	minimum 100:1	average 200:1
Response Time open to closed (90 - 10%)	minimum 15 μs	maximum 150 μs
Response Time closed to open (10 - 90%)	minimum 15 μs	maximum 150 μs
Driver Requirement	± 5 volts	
Duty Cycle	50% (maximum)	
Switching Frequency	5 kHz (maximum)	
Operating Temperature	**20° to 30° C**	
Storage Temperature	0° to 60° C	

2.3 Characterization of BNS ferroelectric spatial light modulators
Final reprt WP A.1.3 - SLM:s
J-P Brichta

Size	3.584mm x 3.584mm
Pixel Pitch	7μm
Fill Factor	77%
Contrast Ratio	200:1 (zero order)
Optical Response (10%-90%)	50-200μs
Maximum Frame Rate	1017 Hz

Table 1. Characterisation parameters of interest.

Most commercially available spatial light modulators are built around nematic liquid crystals
(NLC) or a special form of smectic liquid crystals, the smectic-C* phase or ferroelectric liquid crystals (FLC).
Typically, NLC devices will take 100μs for the molecules to align themselves with the field, and 20ms for the molecules to relax back to their original states. FLC devices are considerably quicker, with modulation switching times on the order of 50μs.

CONCLUSIONS
The characterization of the BNS SLMs was performed using techniques from the literature, although some of these techniques had to be modified due to differing technologies and equipment constraints.
In general, the SLMs have performed according to the specifications provided by Boulder Nonlinear Systems. Both SLMs are able to achieve contrast ratios of at least

200:1 at full modulation, achieve phase modulation in the bipolar mode and provide adequate spatial modulation. At low modulation frequencies, the SLMs exhibit non-linear modulation profiles, though these curves become linear as the modulation frequency increases.
Repeatability issues remain a concern. Irregularities in the SLM zero axis lead to very different results for the same experiments. This unfortunately means that the number of unique, distinguishable GLs may be quite low, perhaps as low as 3-bit (8-level) resolution. A warm-up period of 1-2 hours, or adding cooling devices should help alleviate this problem.
The rise time and fall time of the modulators is satisfactory in the bipolar mode (approximately 200µs) but somewhat long in the pure amplitude mode (300µs). The driving electronics give very regular signals, and the synchronisation signals are compliant with the specifications of major manufacturers e.g. Dalsa or Photosonics.
The mathematical model, based on Jones calculus, is fairly robust and is a useful tool.

2.4 JET PROPULSION LABORATORY
Devices are based on **BOULDER NONLINEAR SYSTEMS, INC.** developments.

JPL

Compact Holographic Memory Using
Electro-optic Beam Steering Devices

Performance Characteristics of LC Beam Steering Device

- Number of pixels: 4096 Reflective
- VLSI backplane in ceramic PGA carrier
- Array size: 7.4 x 7.4 mm
- Pixel size: 1µm wide by 7.4mm high Pixel pitch: 1.8 µm
- Response time:
  - 200 frames/sec with Nematic Twist Liquid Crystal
  - 2000 frames/Sec with Ferroelectric electric Crystal (under development)

Specification	High-voltage SLM
Aperture Size	$\geq$ 19.0mm x 19.0mm
Resolution	12,160 x 1 (all independently addressed)
Pixel Pitch	$\leq$ 1.6 µm
Efficiency	> 90% @ 0° > 60% @ $\pm$ 10° for λ > 1 µm
Data refresh rate	> 10,000 frames per second
New-data frame rate	1,000 frames per second
Modulation	0 to 2π for 530nm < λ < 2060nm
LC response time for 2π stroke	< 1 millisecond
Gray-scale addressing	8 bits per pixel
[illegible]	[illegible]

JPL

Holographic Data Storage

Tien-Hsin chao
Jet Propulsion Laboratory
4800 Oak Grove Drive, Pasadena
California, 91109
Phone:+818-354-8614 FAX: +818-354-1545
E-mail: Tien-Hsin.Chao@jpl.nasa.gov

Presented at the THIC Meeting at the Bahia Hotel
998 West Mission Bay Dr, San Diego CA 92109
on January 16, 2001

JPL

New 512 x 512 Grayscale Spatial Light Modulator

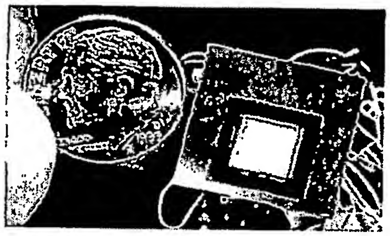
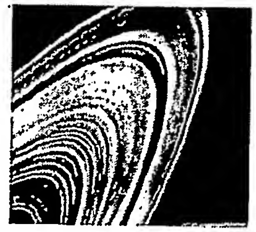


Photo of the new FLC SLM, much smaller than a dime



A high-quality grayscale image readout from the SLM

- New Grayscale SLM has been developed by Boulder Nonlinear System Inc. under a NASA/JPL SBIR Phase II program (T.H. Chao is the JPL contract monitor
  - 512 pixel x 512 pixel, 7-µm pixel pitch, 3.6 mm x 3.6 mm aperture size
  - High-speed at 1000 frames/sec
  - Enable high-density, high transfer rate data storage
  - Enable further system miniaturization

3. Research Center "Vavilov State Optical Institute".

FAST SWITCHING LC DEVICES

Intended for fast light modulation and switching in laser systems and fiber optic communication lines.

<u>ELECTROCLINIC LC SHUTER</u>

Performance characteristics

Aperture	according to customer's requirements
Contrast	> 200
Speed of response (ON/OFF)	5 µs
Angle of optical axis deflection	± 10° - 12° at control voltage < ±25 V

FERROELECTRIC LC SHUTTER

Performance characteristics

Aperture	Up to 45 mm in diameter (according to customer's requirements)
Contrast	> 1000
Speed of response (ON/OFF)	25 μs
Angle of optical axis deflection	From ±22.5° to 40° at control voltage < ±25 - 30 V

4. Displaytech Shutters are used to modulate the polarization state of light or to control whether light is transmitted or reflected at boundaries. Our devices are based on Ferroelectric Liquid Crystal (FLC) technology. Displaytech Shutters blend the speed of electronic shutters and the vibration free operation of standard liquid crystal shutters. The FLC shutter offers exposure times of 1/5,000 of a second while standard liquid crystal shutters may offer exposure times of only 1/100 of a second.

Shutters are used in applications where light must be rapidly switched on/off or where the polarization state of light needs to be switched. They are suited for laser chopping, stereo vision, image capture (freeze-frame), and machine vision. Shutters are used: as switchable color filters to generate color images using high resolution black and white image sensors; for movie conversion from film to digital format; scientific instruments such as microscopes and astronomical telescopes.

Displaytech Shutters are based on electrically switchable FLC halfwave plates. By sandwiching an FLC cell between crossed linear polarizers, the device acts as an intensity modulator. **Switching speeds are above 7 kHz** offering precise, vibration free operation. Shutter control is achieved when 5-volts is applied across its lead holding it in one state. To change states, the polarity is reversed. Our shutters can achieve a modulation depth of 30 db (or **1000:1 contrast ratio**).

Most of our shutters are built for visible wavelengths. However, **we have built shutters for use at 1.55 mm telecom wavelength and mid-infrared wavelengths**. Experimental shutters have been built for use at near-uv wavelengths.

Standard shutters are offered in four aperture sizes and two housing options:

- 13mm - circular housing
- 25mm - circular or square housing
- 45mm - circular housing
- customized aperture sizes

III. Multiple Quantum Wells (MQW) Switches and Modulators.

1. A semiconductor-based optical switch based on GaAs Multiple Quantum Wells (MQW).

The Naval Research Labo ratory.

The concept of a modulating retro-reflector is an old one. However, until recently, modulators have not been available that could support a link at reasonable communications data rates.

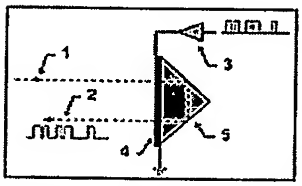


Figure 1. A modulating retro-reflector.

To be viable, the shutter must have a high switching speed, low power consumption, large area, wide field-of-view, and high optical quality. It must also function at wavelengths where good laser sources are available, be radiation-tolerant (for space applications), and be rugged. Mechanical shutters, for example, are too slow and heavy, and ferroelectric liquid crystal (FLC) devices are too slow (kilobits per second) and are not robust enough. To extend modulating retro-reflector links to data rates of megabits per second (Mbps) and higher, and to payloads that must operate over large temperature swings characteristic of installation out-of-doors and in space, NRL has pursued the use of a different type of electro-optic shutter. Specifically, we have been developing a semiconductor -based optical switch based on GaAs Multiple Quantum Wells (MQW). Figure 1 illustrates the concept of a modulating retro-reflector.

MULTIPLE QUANTUM WELL MODULATORS

Semiconductor MQW modulators are one of the few technologies that meet all the requirements described above. When used as a shutter, MQW technology offers many advantages: it is robust and all solid state, **operates at low voltages (less than 20 V) and low power (tens of milliWatts),** and is capable of very high switching speeds. MQW modulators have been run at Gbps data rates in fiber optic applications.

The MQW modulators used in this program were grown at NRL by molecular-beam epitaxy (MBE). The modulators consist of about 75-100 very thin (~10 nm) layers of several semiconductor materials, such as GaAs, AlGaAs, and InGaAs that are epitaxially deposited on a large (7.62 cm diameter) semiconductor wafer. Electrically, they take the form of a P-I-N diode. Optically, the thin layers induce a sharp absorption feature at a wavelength that is determined by the constituent materials and the exact structure that is grown.

When a moderate (~15V) voltage is placed across the shutter in reverse bias, the absorption feature changes, shifting to longer wavelengths and dropping in magnitude. Thus, the transmission of the device near this absorption feature changes dramatically. Figure 2 shows absorbance data for an InGaAs MQW modulator designed and grown at NRL for use in a modulating retro-reflector system. The figure illustrates how the application of a moderate voltage shifts the transmittance. Hence, a signal can be encoded in an On-Off-Keying format onto the carrier interrogation beam.

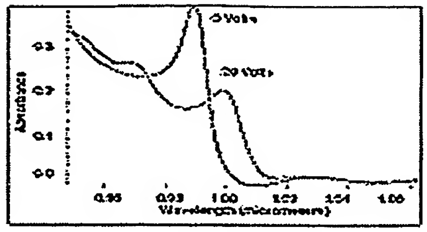


Figure 2. Absorbance vs. Frequency

This modulator consists of 75 periods of InGaAs wells surrounded by AlGaAs barriers. The device is grown on an n-type GaAs wafer and is capped by a p-type contact layer, thus forming a P-I-N diode. This device is a transmissive modulator designed to work at a wavelength of 980 nm, compatible with many good laser diode sources. GaAs/AlGaAs modulators that work at 850 nm have also been grown. These materials have very good performance and operate in reflection architectures. Choice of modulator type and configuration architecture is application-dependent.

Once grown, the wafer is fabricated into discrete devices using a multi-step photolithography process consisting of etching and metallization steps. The NRL experimental devices have a 5-mm aperture, though larger devices are possible and masks for one centimeter devices are currently being designed as well. It is important to point out that while MQW modulators have been used in many applications to date, modulators of such a large size are uncommon and require special fabrication techniques. Figure 3 shows a block diagram and photo of a wide aperture MQW shutter designed, grown, and fabricated at NRL.

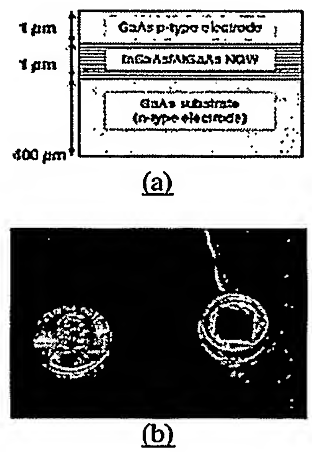


Figure 3. (a) A schematic of a MQW modulator. (b) A fabricated .5cm transmissive device.

MQW modulators are inherently quiet devices, faithfully reproducing the applied voltage as a modulated waveform. An important parameter is contrast ratio, defined as Imax/Imin. This parameter affects the overall signal-to-noise ratio. Its magnitude depends on the drive voltage applied to the device and the wavelength of the interrogating laser relative to the exciton peak. The contrast ratio increases as the voltage goes up until a saturation value is reached. Typically, **the modulators fabricated at NRL have had contrast ratios between 1.75:1 to 4:1 for applied voltages between 10 V and 25 V**, depending on the structure.

There are three important considerations in the manufacture and fabrication of a given device: inherent maximum modulation rate vs. aperture size; electrical power consumption vs. aperture size; and yield.

For example, a one centimeter monolithic device might require 400 mW to support a one Mbps link. A similar nine segmented device would require 45 mW to support the same link with the same overall effective aperture.

2. Large Aperture Quantum Well Shutters for Fast Retroreflected Optical Data Links in Free Space.

by

G. Charmaine Gilbreath, W. S. Rabinovich, Rita Mahon*,
Michael R. Corson+, Mena Ferraro-, D. S. Katzer, K. Ikossi-Anastasiou,
Timothy Meehan, and John F. Kline+
Naval Research Laboratory
Washington, D. C. 20375

ABSTRACT

This paper reports progress on the development of a fast modulating retroreflector for a free space optical data link. A previous publication reported sustaining video over a 17 meter link using a multiple quantum well shutter with a diameter of 0.5 cm at a rate on the order of 0.5 Mbps, limited by the demonstration electronics. This work describes improvements in the device performance, which is on the order of 4 Mbps to 6 Mbps with a Bit Error Rates of 10^{-6} over a robust optical link. This device lends itself to an array configuration for long range applications and will clearly support T1 rates of 1.54 Mbps, and higher.

Using a BER of 10^{-6} which is typically acceptable in a given link, devices performed **at a rate of 4 Mbps and 6 Mbps respectively in the non-photon limited case using a 4 mm diameter MQW shutter.**

Specifically, for a 6 Mbps link at a drive voltage of 5V, the required power for the reflective modulator and driver was 40 mW. Similarly, for the transmissive modulator operating at 4 Mbps and 10 V, the required power was found to be 170 mW.

IV. Micro -Electromechanical System (MEMS)

Microelectromechanical Systems

MEMS have a movable or deformable reflective surface on top of a semiconductor chip. The chip generates voltages in response to digital information. The voltages change the shape of the reflective surface rapidly and in a controlled way to produce the image that was encoded by the digital information. The projected light bounces off the reflective surface and gets collected by the projector lens.

IS TELECOM READY TO EMBRACE MEMS-BASED SOLUTIONS?

By Marlene Bourne

Small Times columnist

What's different is product focus. Gone are the days of mass pursuit of super-sized cross-connects (the mega switches). These days, of the 20 companies pursuing

MEMS switches, only three are offering anything larger than 16x16: Calient Networks, Glimmerglass Networks and Movaz Networks.

Most of the remaining companies have concentrated on 1x2 and 2x2 arrays. The focus has shifted to Variable Optical Attenuators (VOAs), with more than a dozen companies in this space (and most of them also offering switches). In fact, this is where much of the revenue generation is occurring right now.

1. MEMS Optical Inc.

A scanning two axis tilt mirror.

Specifications

- *Mirror Size:* 520µm across
- *Reflective area:* 510µm across
- *Shape:* Octagonal
- *Surface reflectivity:* >95% at 630nm (gold)
- *Bias voltage:* 55 Volts
- *Drive voltage:* 0÷110 Volts
- *Maximum tilt angle:* +/- 3° mechanical
- *Resonant rotation frequency:* outer axis 1.3 kHz, inner axis 1.8 kHz.
- *Operating Temperature:* 0÷50° C
- *Radius of Curvatu re:* >.4 meters within operating temperature
- *Array Pitch:* 1.5mm(custom spacing available)

A moving mirror for tunable lasers.

One of the products that MEMS Optical can produce is a moving mirror for tunable lasers. When put inside the laser cavity, this mirror can be moved by up to 10 to 100 microns. Actuated by MEMS Optical's patented vertical comb drive, this allows a simple and effective way of changing the path length inside the laser cavity.

2. Applied MEMS, Inc.

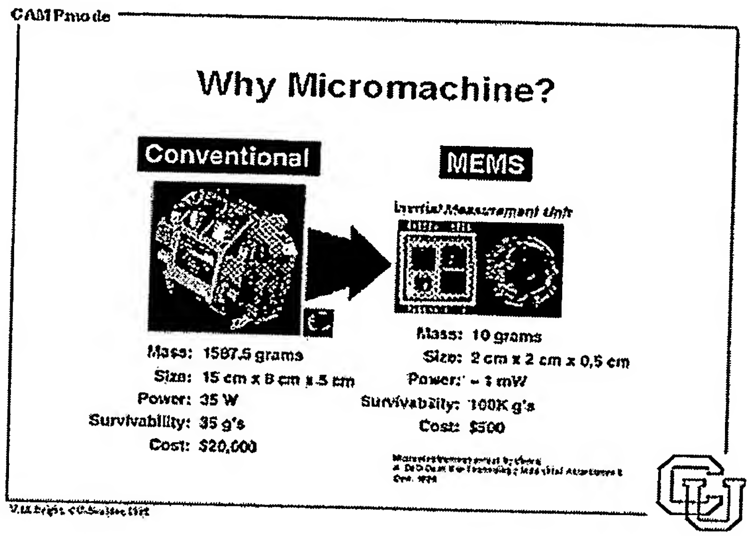
Future MicroMirro Product Specifications (Preliminary Data)

Criteria	DuraScan™	Digital-8™ (Phase #1)	Digital-8™ (Phase #2)
Mirror (L x W x H)	3 x 3 mmx400um	1.5 x 1.5 mm x60um	1.5 x 1.5 mmx10um
Die size (L x W x H)	6.8 x 4.1 x 1.5 mm	6.5 x 4.8 x 1.0 mm	6.5x4.8x1.0 mm
Max Rotation angle RY axis RX axis	 +/- 12° +/- 1°	 +/- 6° (± 0.1°) +/- 3.7° (± 0.1°)	 +/-1.8° (± 0.01°) +/- 1.1° (± 0.01°)
Resonant frequency	40 ~ 50 Hz RY 670 Hz RX	318 Hz RY 840 Hz RX	318 Hz RY 840 Hz RX
Actuation voltage	330 V RY (DC) 970 V RX (DC) (scanning = 0.3* DC voltage)	149 V RY (digital) 400 V RX (digital)	11 V RY (digital) 32 V RX (digital)
Shock tolerance	2000g all axes (0.5 ms - ½ sine)	2000g all axes (0.5 ms - ½ sine)	1000g all axes (0.5 ms - ½ sine)
Optical flatness In 0 – 70 °C	Radius curvature > 800 cm	Radius curvature > 150 cm	Radius curvature > 150 cm
Surface quality	Roughness < 3 nm Reflectivity ~ 96%	Roughness < 3 nm Reflectivity ~ 96%	Roughness < 3 nm Reflectivity ~ 96%

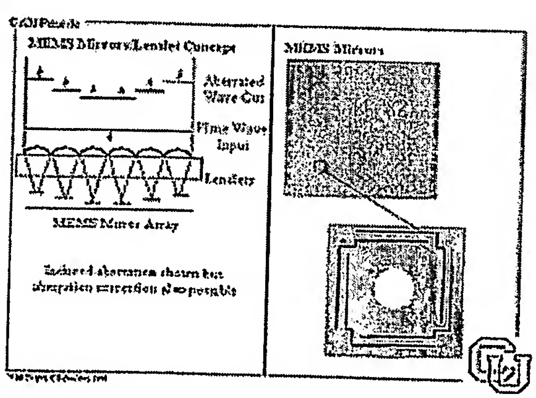
3. Surface Micromachined Optical Systems.

Prof. Victor M. Bright
Associate Professor
University of Colorado
brightv@colorado.edu

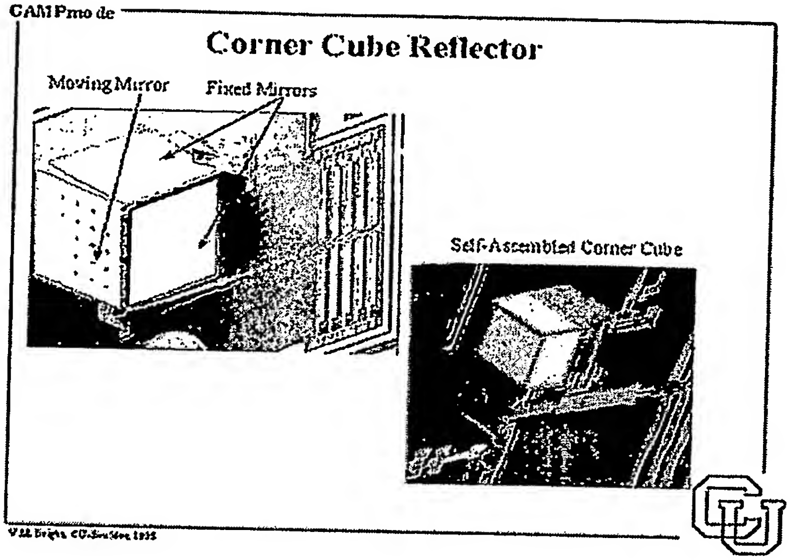
Slide 003. Why Micromachine?



Slide 010. MEMS Mirrors



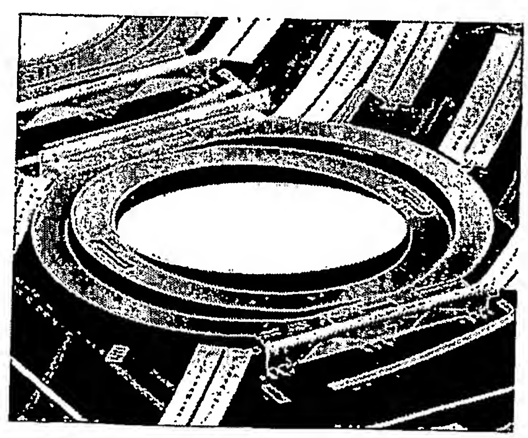
Slide 033. Corner Cube Reflector



4. **Lucent's New All-Optical Router Uses Bell Labs Microscopic Mirrors**

Based on Bell Labs' patent-pending technology, Lucent's WaveStar(TM) LambdaRouter uses a series of microscopic mirrors to instantly direct and route optical signals from fiber to fiber in the network, without first converting them to electrical form as done today. This will save service providers up to 25 percent in operational costs and enable them to direct network traffic 16 times faster than electrical switches.

All 256 mirrors are fabricated on less than one square inch of silicon. This compact switching fabric provides more than 32 times greater switching density than electronic fabrics today. And with no optical-electrical-optical conversion, the LambdaRouter switch fabric will provide up to a 100-fold reduction in power consumption over electronic fabric solutions.



A MICRO-MIRROR THAT ROUTES INFORMATION – One of an array of 256 microscopic mirrors, each the size of the head of a pin, tilts to steer lightwave signals from one optical fiber to another in Lucent Technologies' WaveStar(tm) LambdaRouter, invented at Bell Labs.

5. Digital Mirror Devices (DMD)

Digital Micromirror Device (DMDTM) by Texas Instruments.

The DMD light switch is fabricated by CMOS processes over conventional CMOS/SRAM
circuitry, and is the key to the Digital Light Processing (DLPTM) Technology developed by Texas Instruments.
Each pixel in a DMD device contains a square aluminum mirror, fabricated on hinges atop a static random access memory (SRAM) chip. The hinges allow the mirrors to tilt between two states, +10 degrees for "on" or -10 degrees for "off". When the mirrors are not operating, they sit in a "parked' position at 0 degrees. The light reflected by "on" pixels is transmitted on through the projection system, whereas that from the "off" pixels must be absorbed or deflected away. Grey scale is achieved by modulating the incident light using a binary pulsewidth modulation scheme having 8 bits per color, producing 256 gray levels and 16.8 million different color combinations.
The DMD light switch pixel consists of a mirror that is rigidly connected to an underlying yoke. The dimensions of the mirrors have so far been fixed at 16μm square with centers spaced by 17 μm. . The yoke in turn is connected by two thin, mechanically compliant torsion hinges to support posts that are attached to the underlying substrate.
Electrostatic fields developed between the undeelying memory cell and the yoke and mirror cause rotation in the positive or negative direction. The rotation is limited by mechanical stops to +10 or -10 degrees.

At the heart of every DLP™ projection system is an optical semiconductor known as the **Digital Micromirror Device** , or DMD chip, which was invented by Dr. Larry Hornbeck of Texas Instruments in 1987.

A DMD panel's micromirrors are mounted on tiny hinges that enable them to tilt either toward the light source in a DLP™ projection system (ON) or away from it (OFF)-creating a light or dark pixel on the projection surface.
Digital Micromirror Devices (DMD)

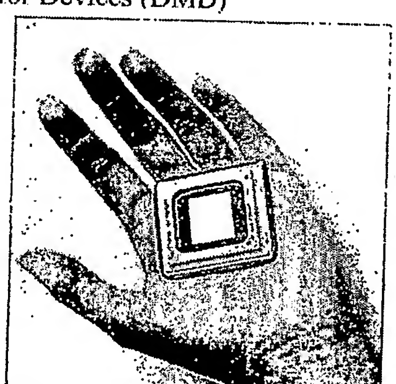


Photo courtesy Texas Instruments **SXGA DMD (1280 x 1024 pixels, 1,310,720 mirrors)**

DMDs, also called **digital light processing** (DLP), were developed by Texas Instruments. The DMD is a chip that has anywhere from 800 to more than 1 million tiny mirrors on it, depending upon the size of the array.

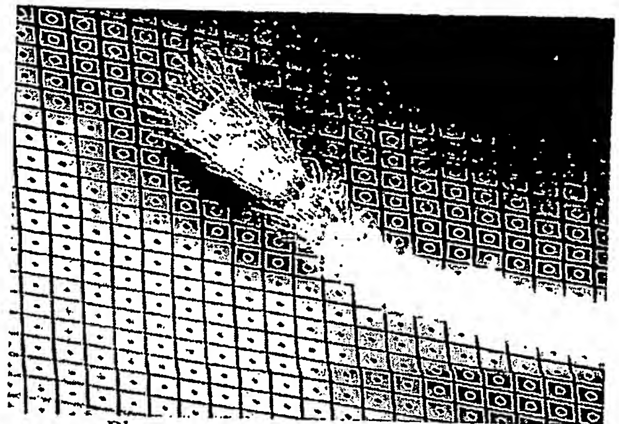


Photo courtesy Texas Instruments

Micrographic photo of ant leg on the DMD surface: Each mirror is 16 μm^2, with 1 μm separation between pixels.

Each mirror rests on support hinges and electrodes.

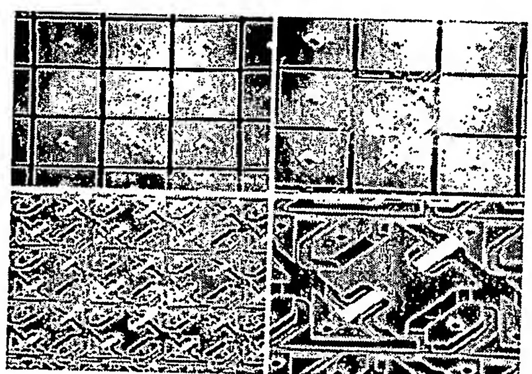


Photo courtesy Texas Instruments

The top left view shows nine mirrors. In the top right, one central mirror was removed to expose the underlying hidden-hinge structure. The bottom right shows a close-up view of the mirror substructure. The mirror post, which connects to the mirror, sits directly on the center of this underlying surface. The bottom left shows several pixels with the mirror removed.

The bit-streamed image code entering the semiconductor directs each mirror to switch on and off **up to several thousand times per second**. When a mirror is switched on more frequently than off, it reflects a light gray pixel; a mirror that's switched off more frequently reflects a darker gray pixel.

6. Activated Mirror Array (AMA).

This device, developed by Aura Systems and Daewoo, also operates by tilting individual mirrors in an array, using the piezoelectric effect. However, whereas the DMD is essentially a binary device, the AMA is fundamentally an analog device and is therefore capable of analog gray scale without the frame-sequential addressing used driving the DMD.

7. Grating Light Valves (GLV).

A GLV is also a micro-electromechanical system (MEMS) consisting of parallel rows of reflective ribbons.
Alternate rows of ribbons can be pulled down approximately one-quarter wavelength to create diffraction effects on the reflected light. When all the ribbons are in the same plane, incident light is reflected specularly from their surfaces. If the incident light is normal to the surface, so is the reflected light. By blocking light that returns in the specular direction, this state of the ribbons produces a dark spot in the image. When the alternate ribbons are pulled down, diffraction produces light at a different angle that is determined by the wavelength of the light and the mirror spacing. If this direction is unblocked, a bright spot is created in the image. If an array of such GLV elements is built and sub-divided into separately controllable pixels, then a white source can be selectively diffracted to produce an image of monochrome bright and dark pixels By making the ribbons small enough, pixels can be built with multiple ribbons producing greater image brightness. Since **the ribbons can be switched rapidly between up and down states, in times of the order of 20 ns**, time modulation of the diffraction can produce many gradations of gray and/or colors.
GLV technology, licensed to Sony, was developed by Professor David Bloom at Stanford University, and is now produced by Silicon Light Machines in Sunnyvale, California.

The GLV chip consists of tiny **reflective ribbons** mounted over a silicon chip. The ribbons are suspended over the chip with a small airgap in between. When a voltage is applied to the chip below a ribbon, the ribbon moves toward the chip by a fraction of the wavelength of the illuminating light. The deformed ribbons form a diffraction grating, and the various orders of light can be combined to form the pixel of an image. The shape of the ribbons, and therefore the image information, can be changed in as little as 20 billionths of a second.

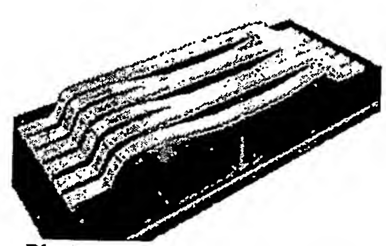


Photo courtesy Silicon Light Machines
Diagram of a single grating light valve pixel on a GLV chip

8. ASSEMBLED CORNER-CUBE RETROREFLECTOR QUADRUPLET
Lixia Zhou, Kristofer S. J. Pister and Joseph M. Kahn
Department of Electrical Engineering and Computer Sciences
University of California, Berkeley, CA 94720 USA, {lzhou, pister, jmk}@eecs.berkeley.edu

ABSTRACT
A MEMS corner-cube retroreflector (CCR) is presented. It is used as the free-space optical communication transmitter in the Smart Dust project. The optical and electrical properties are greatly improved as compared to CCRs fabricated previously in the MUMPS process[1, 2].
Experiment demonstrate a DC pull-in voltage as low as 5 V and a pull-in angle of approximately
0.44? full, in good agreement with theoretical predictions. The resonant frequency occurs at 1.3 kHz while the 3-dB cut-off frequency is around 2.1 kHz. A higher resonant frequency is achievable by decreasing the thickness of device layer of SOI wafer.
The energy consumption per bit, roughly 40 pJ (the sensor plate size of 500 μm), is consistent with the power requirements of a millimeter-scale autonomous sensor node [4].

Summary:

Name and Contacts	Aperture Size, mm*mm	Optical Response Time, μs	Frame Rate, kHz	Contrast Ratio	Energy Consumption per 1 cm² of Aperture per bit, μJ	Temp. Range, ℃	Cost, $
Nematic LC: Zenithal Bistable Device, ZBD Displays Limited, Samantha Fletcher at Berkeley Public Relations Tel: 01629 826 942 E-mail: samanthaf@ Berkeleyprnorth.co.uk, Or customer service team Tel: 01684585310, Or Varitronix Limited	20x20 53x53 20x20	80 400	2.5 0.025	130 25 40	(21.7V) (30V) 0.04	-20÷80	
Nematic LC: NEMOPTIC, France The BiNem® technology Alain Boissier, President and CEO of NEMOPTIC a.boissier@nemoptic.com	55x55	30		10	1.1 (15)		
Supertwist Nematic (STN) Liquid Crystal Display	30x30		0.060		0.28		
Nematic LC: MicroDisplay, MD1280P4E_WX 1280x768 LCOS	18x11		0.540		370 (12V)		
Ferro-Electric LC	11.9x8.9		44				

Over Silicon: Cambridge University Engineering Department, T.D. Wilkinson, N. New, W.A. Crossland.	14x14		22.7	12			
Ferro-Electric LC. Boulder Nonlinear System, Inc., Dr. Ping Wang, Tel: (303) 604-0077. UNIV. OF COLORADO, Tel: (303) 492-3330. Kelly Gregorak, Marketing Manager Boulder Nonlinear Systems 303-604-0077 kelly@bnonlinear.com	1÷150 5÷95	5÷200 15	1.017 3	500 100	(5V) (5V)	20÷30 20÷30	
Ferro-Electric LC: Jet Propulsion Laboratory, Tien-Hsin Chao, Tel: +818-354-8614, Fax: +818-354-1545, E-mail: Tien-Hsin.Chao@ jpl.nasa.gov	19x19		1				
Ferro-Electric LC: Research Center "Vavilov State Optical Institute"	Up to 45	25		1000	(30V)		
Ferro-Electric LC: Displaytech Shutters **Multiple Quantum Wells** (GaAs). The Naval Research Laboratory,	25x25 4x4		7 6,000	1000 4	(5V) 0.04 (5V)		
MEMS: MEMS Optical Inc.	0.5x0.5		1.3		(55V)	0÷50	
MEMS: Applied MEMS, Inc.	1.5x1.5		0.840		(32)		
MEMS: Surface Micromachined Optical System, University of Colorado, Prof. Victor M. Bright, E-mail: brightv@colorado.edu	20x20						500
MEMS: Lucent Technologies'							

WaveStar LambdaRouter, invented at Bell Labs.							
MEMS: Digital Micromirror Device (DMD). Texas Instruments			3				
MEMS: Grating Light Valves (GLV). licensed to Sony, was developed by Professor David Bloom at Stanford University, and is now produced by Silicon Light Machines in Sunnyvale, California.		0.02					
MEMS: Corner-Cube Retroreflector. Lixia Zhou, Kristofer S. J. Pister and Joseph M. Kahn Department of Electrical Engineering and Computer Sciences University of California, E-mail; {lzhou, pister, jmk}@eecs.berkeley.edu	0.5x0.5		1.3		12 (5V)		

Conclusions:

1. The Zenithal Bistable Devices that are based on Nematic Liquid Crystals can work at rate of about 10 kbits/sec with about 0.04 μJ energy consumption per bit per 1 cm^2 of the optical aperture.
2. The modulators that are based on Ferro-Electric Liquid Crystals can work at rate of about 44 kbits/sec. But they suffer from problem such as limited temperature range (20÷30°C).
3. The MQW modulators can work at rate of about 6 Mbits/sec with about 0.04 μJ energy consumption per bit per 1 cm^2 of the optical aperture. But they have low contrast ratio (4:1 maximum).
4. The Grating Light Valves MEMS can work at rate of several Mbits/sec.

Claims:

1. System or method for energy saving communication to remote devices, substantially as hereinbefore described with reference to the accompanying drawings.

2. The system or method of claim 1, wherein the remote devices are storage devices.

3. The system or method of claim 1, wherein the remote devices are remote sensing devices.

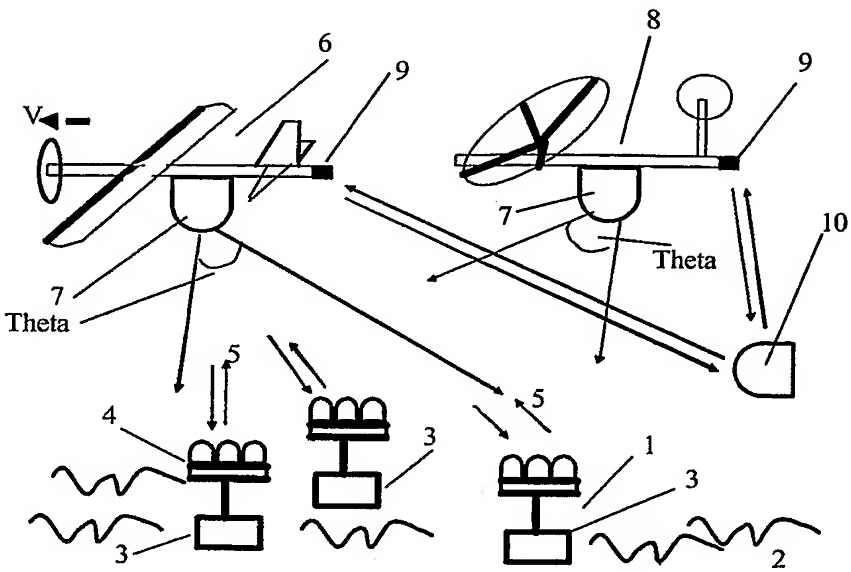


Figure 1

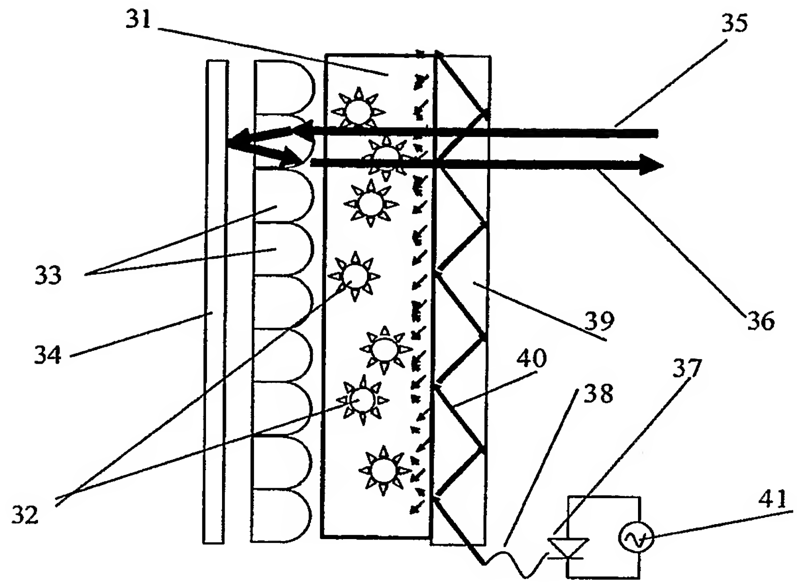


Figure 2a

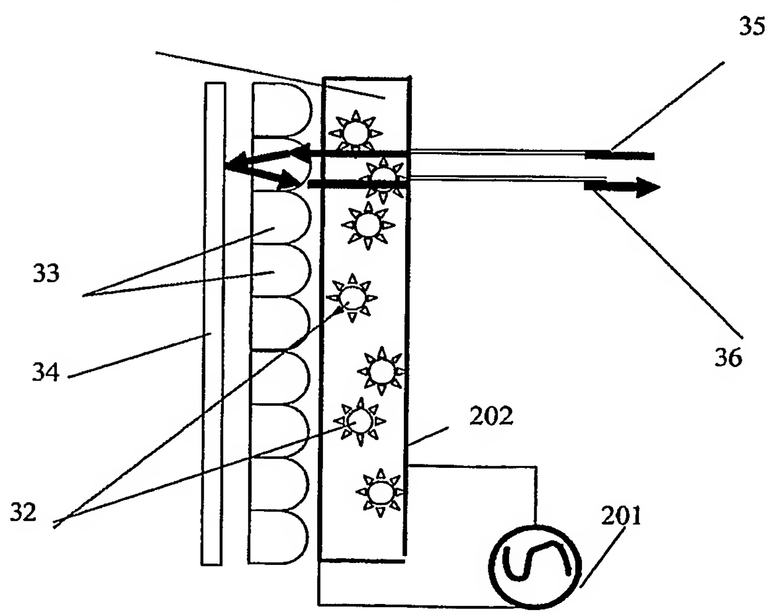


Figure 2b

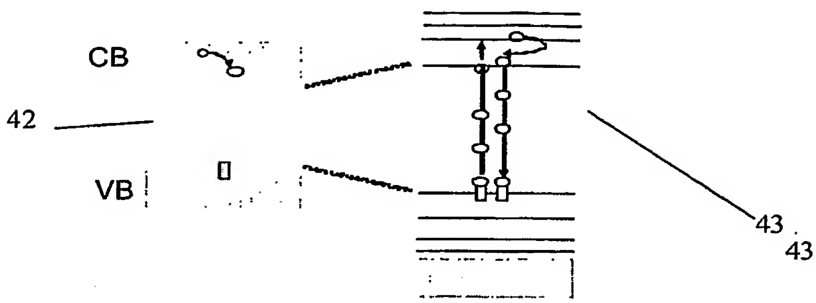


Figure 3

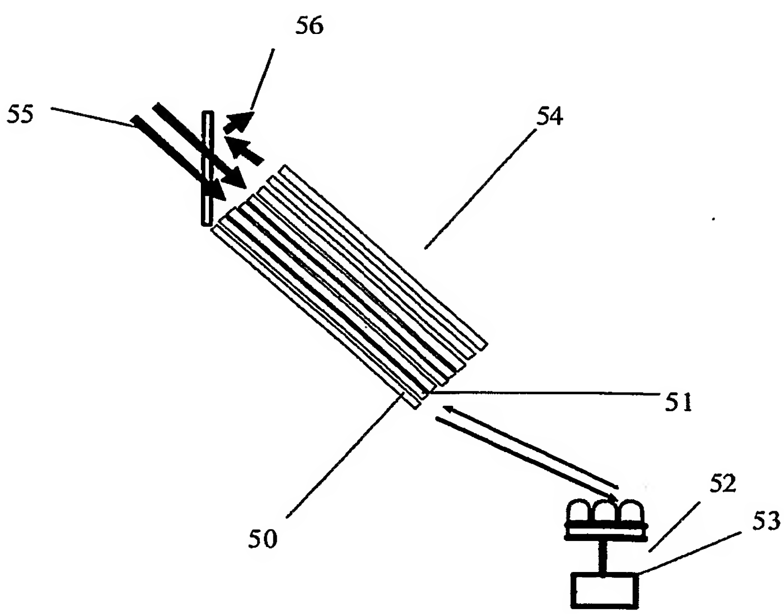


Figure 4

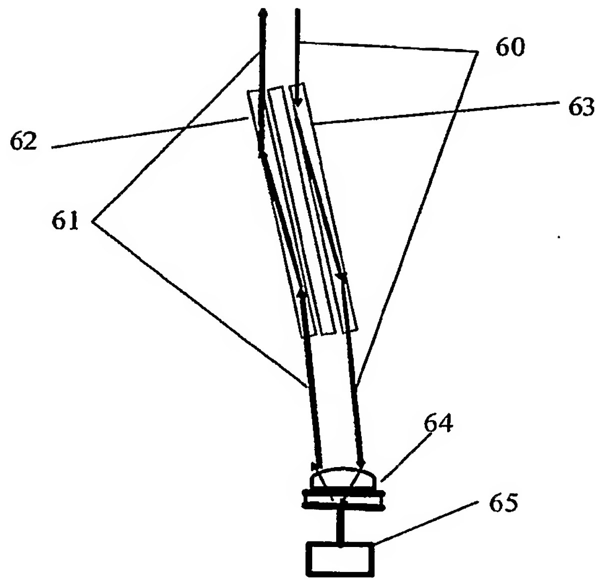


Figure 5

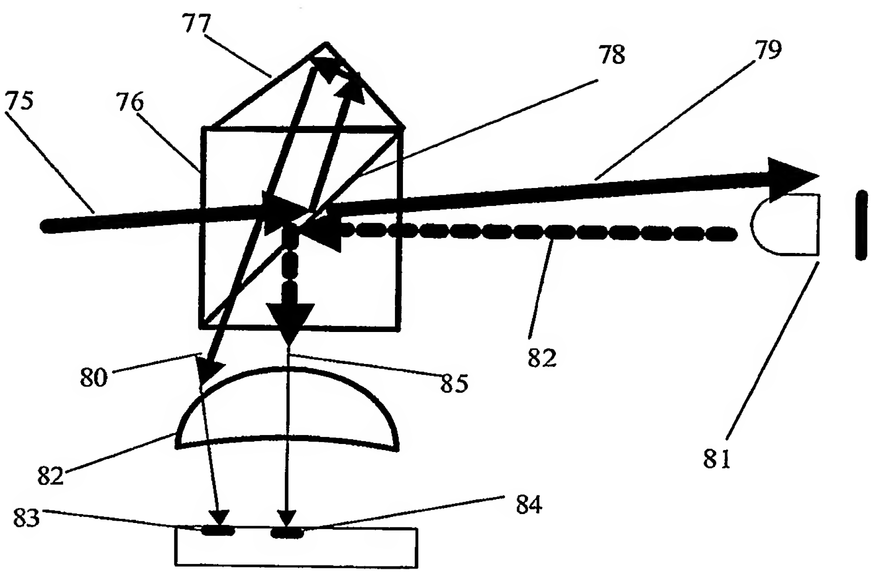


Figure 6

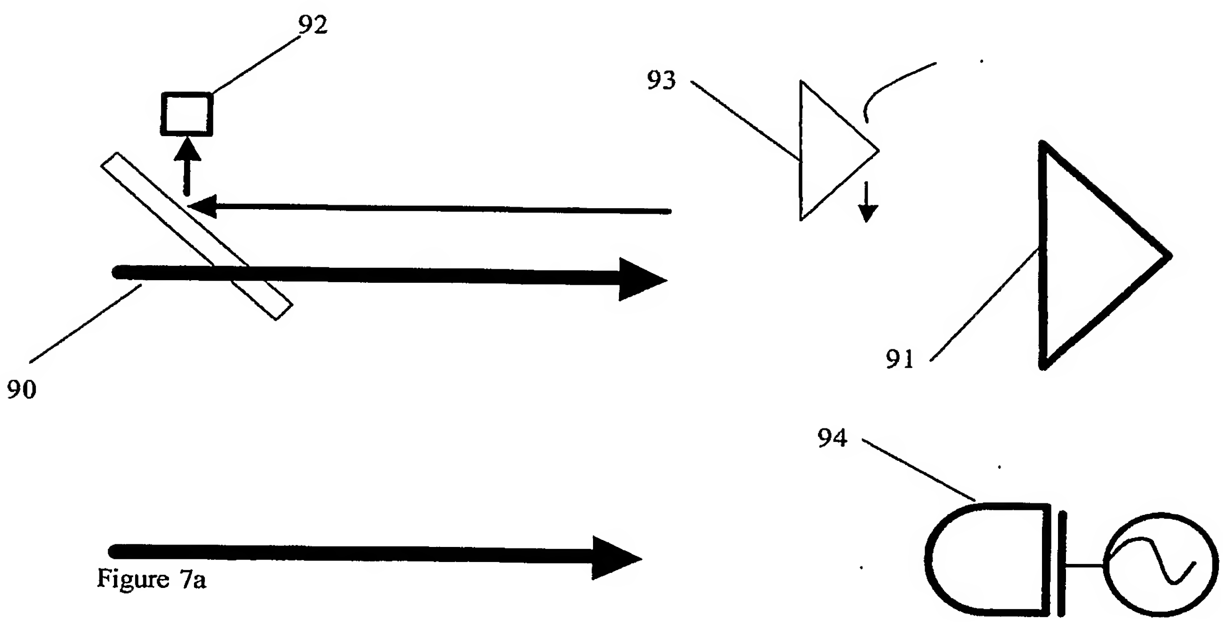


Figure 7a

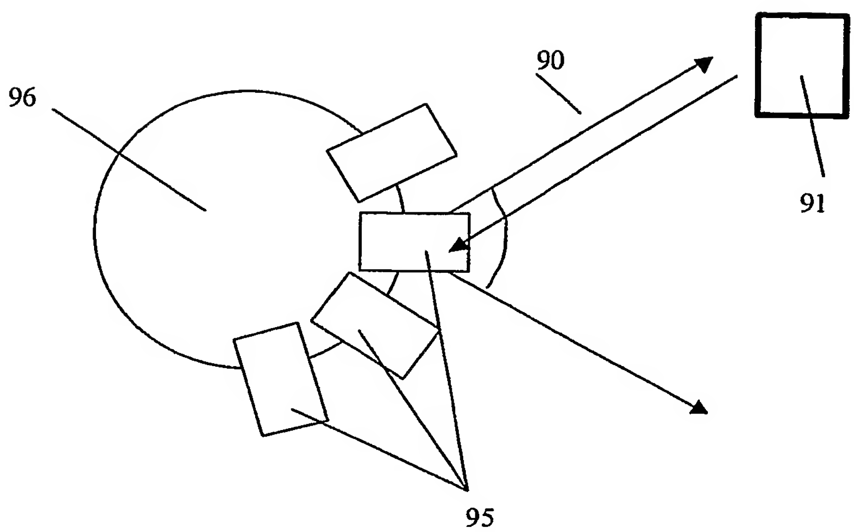


Figure 7b

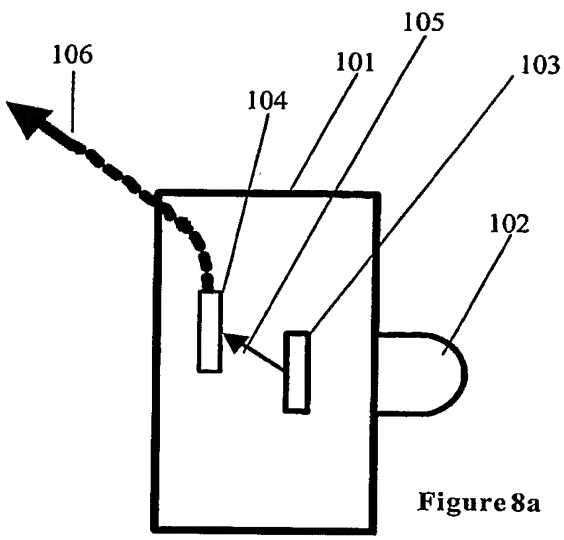


Figure 8a

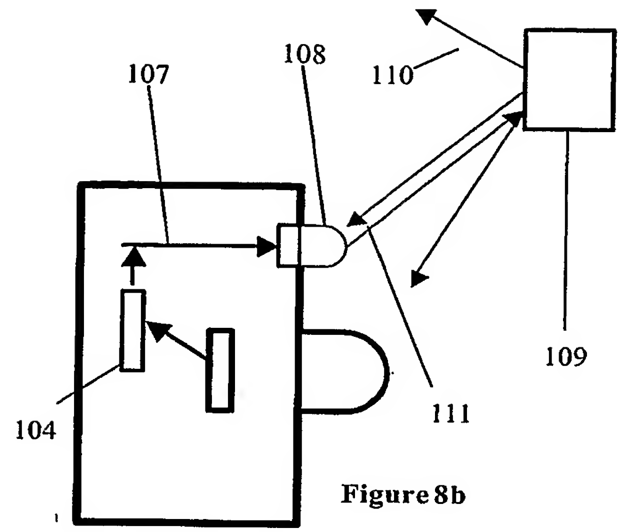


Figure 8b

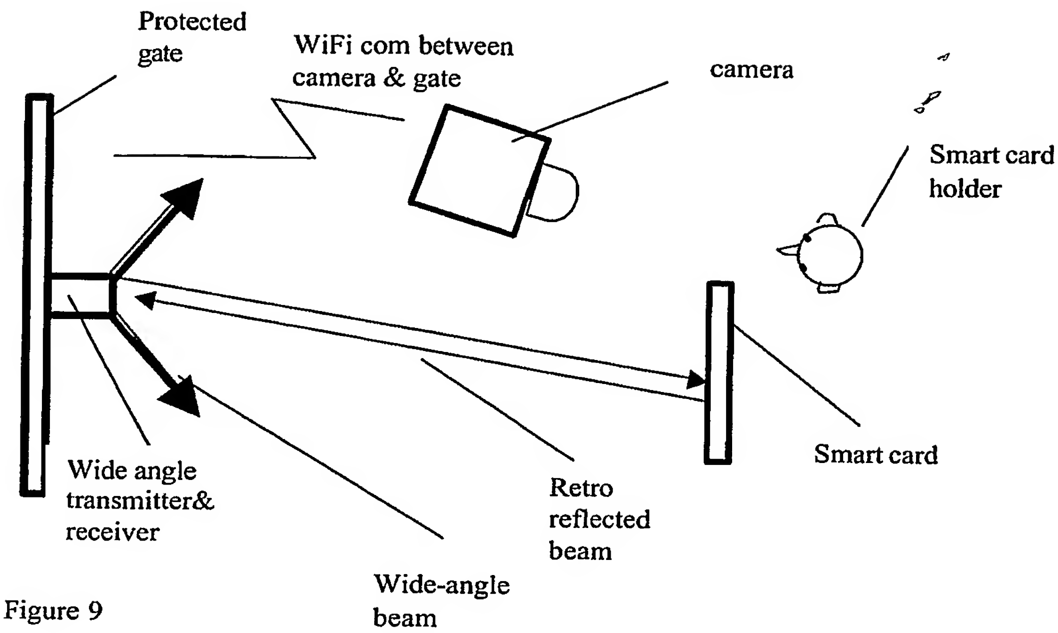


Figure 9

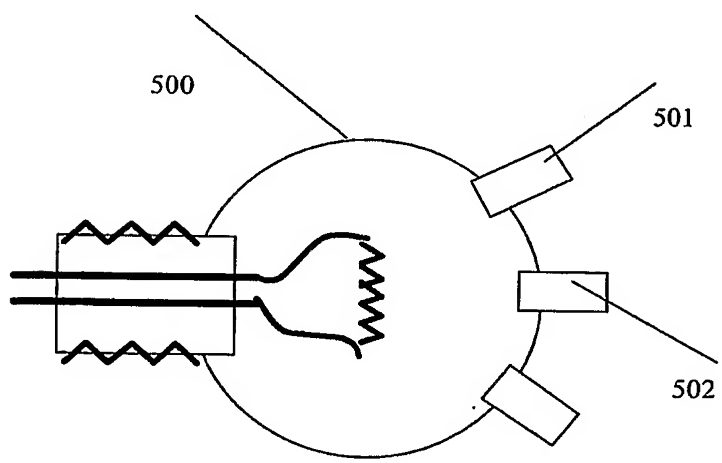
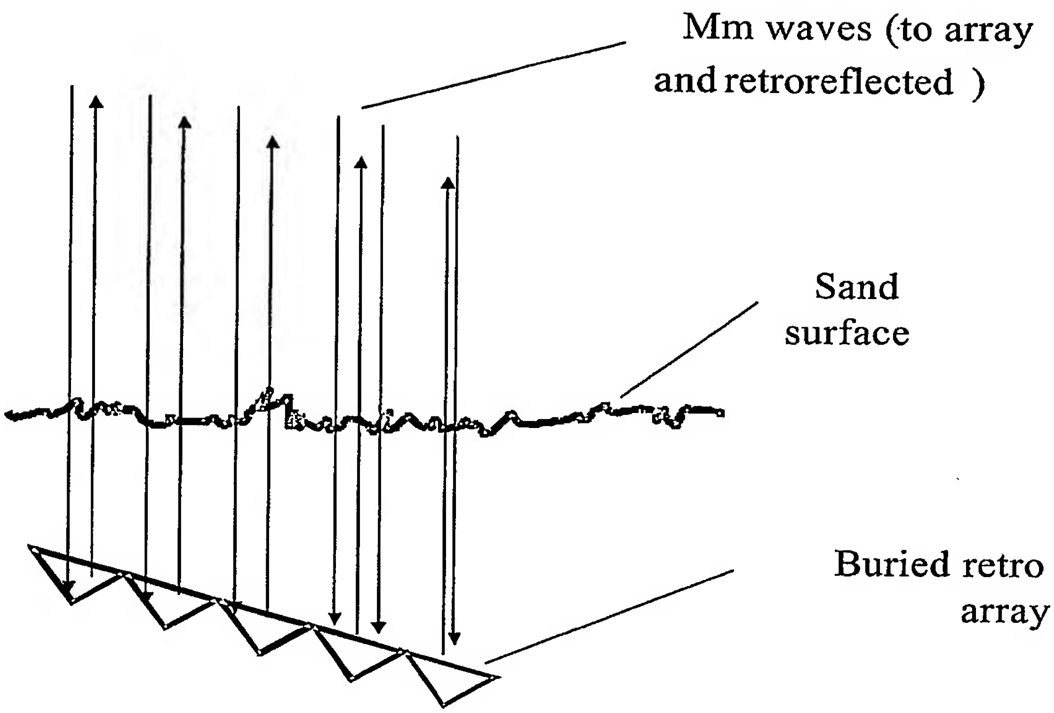


Figure 10

Figure 11:



Mm waves (to array and retroreflected)
Sand surface
Buried retro array

Figure 12 :

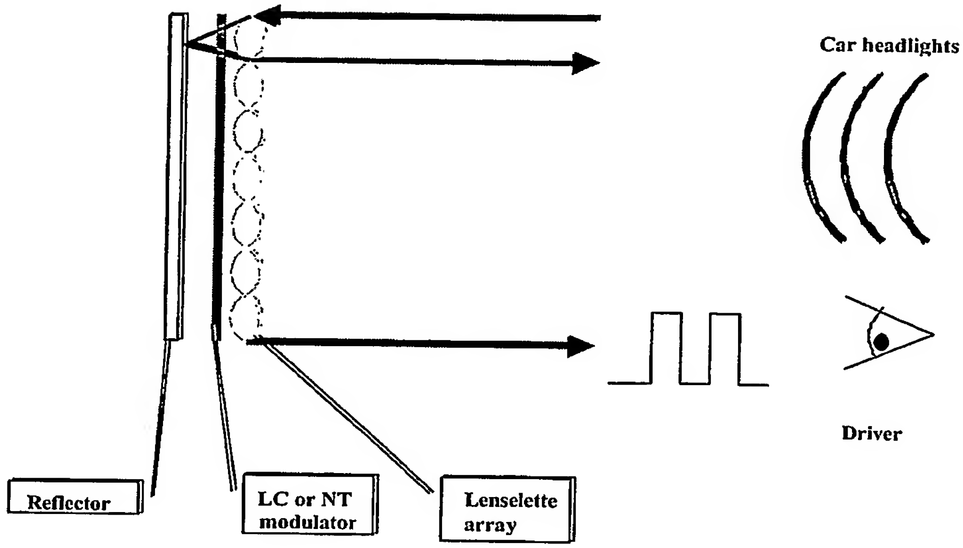


Figure 13:

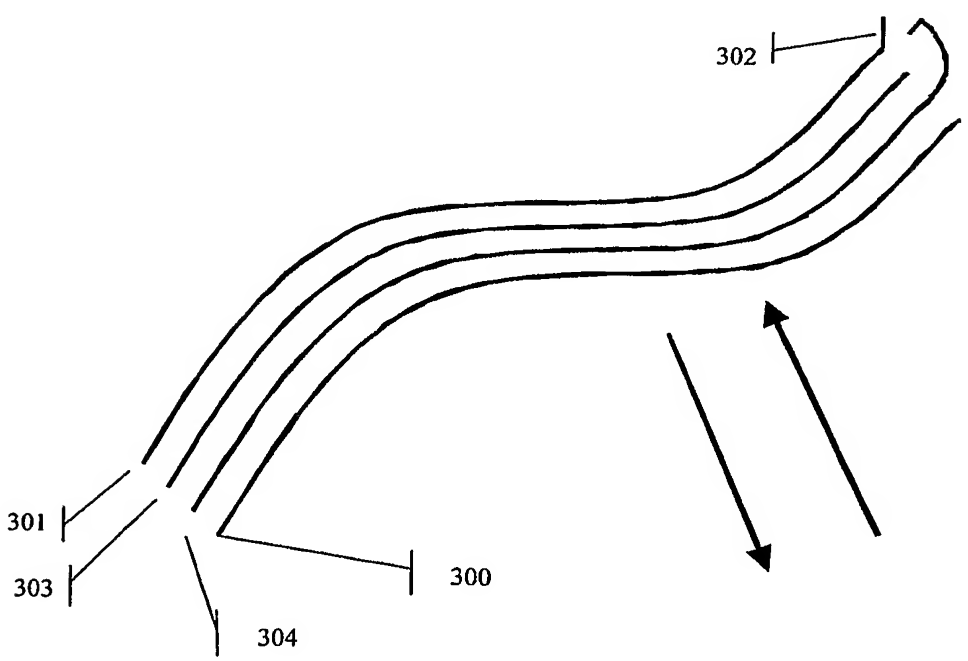


Figure 14:

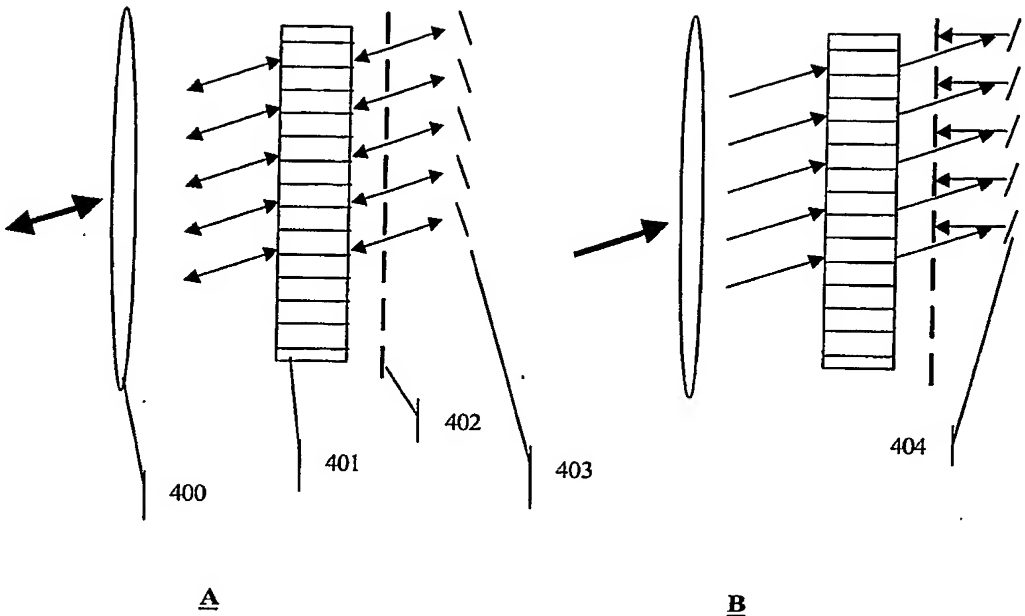


Figure 15: